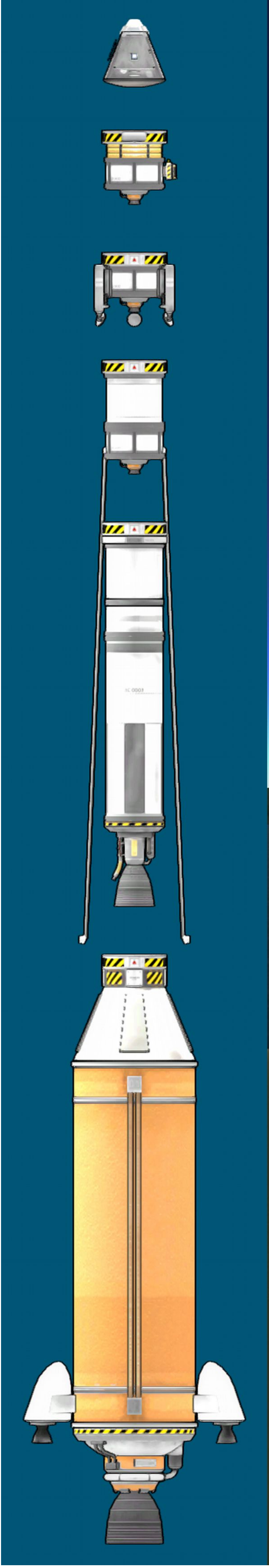

Exploring The System

A Design Tutorial Campaign
For Kerbal Space Program 0.90

By Pecan

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7 Apr 2015 - KSP 0.90, SCANSat 10.0, PF 3.11

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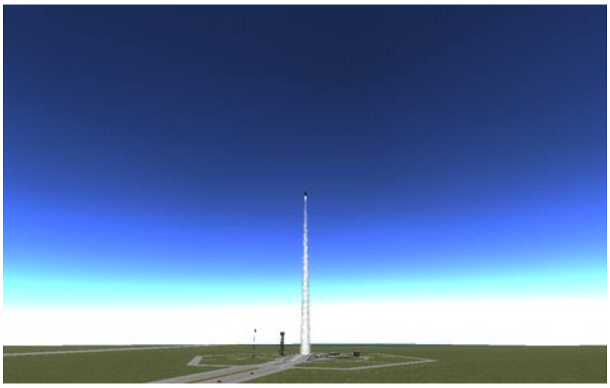
CHAPTER 1: INTRODUCTION

Purpose and organisation.

SECTION 1: PREFACE

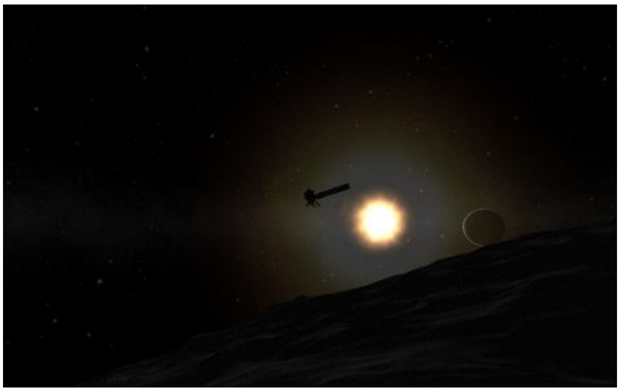
This is a mission and vehicle design tutorial aimed at KSP beginner and intermediate players using a stock installation of the game. It is much longer and more involved than most tutorials, providing and explaining more than 30 vehicles from a rover to interplanetary transfer and space-stations. Four (space)plane designs are included but the focus is very much on rocket design because spaceplanes are hard to build and fly and do not scale well to larger payload sizes.



Launch Into Space

All the vehicles are intended to illustrate one or more design points while being easy to build and use. They are generally robust and capable rather than being 'the best'. Optimised designs tend to be hard for beginners to build and there are several different criteria you may choose to favour over others, so what 'the best' means is up to you. The intention is to explain the reasons for particular design decisions so that you will be able to create your own vehicles, when you want to, with more confidence.

The tutorial is organised into 'project' chapters with a logical progression. Chapter 2 provides 'starter vehicles' for complete beginners who don't yet know how to drive and fly in KSP. Most people will want to start with chapters 3 – 5, which begin by putting unmanned satellites into Kerbin orbit and end with manned landings on Kerbin's moons. The step from 'beginner' to 'intermediate' is marked by Chapter 6 which is a reminder to keep things light. By the time you reach this you should have a fairly good idea of how you want to run your space missions. Chapters 7 and 8 are for more experienced players and look at building a cost-effective, reusable infrastructure throughout the system.



Explore With Small Satellites

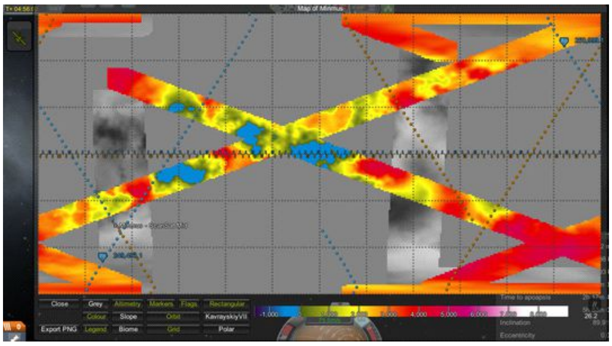
Each chapter begins with a 'project briefing' outlining the background, objectives and vehicles for the project. Within projects each vehicle is introduced with a 'data sheet' giving its most important features. Following the data sheet there is a narrative discussion of the design, construction and staging/action groups. Each vehicle's section usually finishes with a number of missions that should be completed in order to follow the logical progression of the tutorial. It is, of course, up to you whether you actually build the vehicles and fly the missions but you should at least read-through these details.

SECTION 2: THINGS YOU NEED TO LEARN

Although no prior knowledge is assumed during this tutorial an awful lot isn't explained either. I hope I've covered the vehicle design/construction and missions properly but it's largely assumed that you will know, or learn, how to *use* KSP yourself. Many giants have already written or filmed all you need to know, keep your browser handy and bookmark the KSP forum and wiki:

- Wiki: http://wiki.kerbalspaceprogram.com/wiki/Main_Page
- Forum: http://forum.kerbalspaceprogram.com/forum.php
- Tutorials: http://forum.kerbalspaceprogram.com/forums/54-Tutorials
- Guide to tutorials: http://forum.kerbalspaceprogram.com/threads/28352-The-Drawing-Board-A-library-of-tutorials-and-other-useful-information

In particular, as you progress, you should become familiar with the controls for rovers, planes and rockets, getting into orbit, EVA, orbital manoeuvres, landing, rendezvous, docking and interplanetary transfers. In turn these will require that you understand and use figures for TWR, deltaV and (to a lesser extent) ISP. The most important for mission-planning is deltaV and you will almost certainly want to use a deltaV map such as http://i.imgur.com/NKZhU57.png (others are available and all this will be explained, even if not in detail).



Map The System

SECTION 3: MODS

Modifications (mods) are add-ons for KSP made and distributed by ordinary players who have the necessary programming, 3d-modelling and/or graphics skills. Be nice to them, even if you don't like their mod – they are working for free just because they have an idea for making things better for everyone. The best place to find out about mods is, again, on the forum:

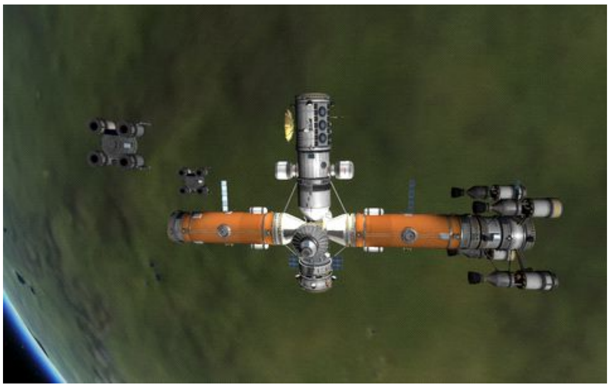
http://forum.kerbalspaceprogram.com/forums/35-Add-on-Releases-and-Projects-Showcase

Some mods can be downloaded from their makers' hosting site (as will be explained in their relevant forum threads), otherwise the standard place to find and get them is Curse:

http://kerbal.curseforge.com/

I tended to use a lot of mods, informational or cosmetic rather than game-changing, but my old computer can't cope with them any more. Be warned that mods, especially those that add a lot of parts, increase the memory and processing requirements for the game. In order to improve the looks and functionality of the vehicles in this tutorial I have used two parts-mods (mods that add/change parts), neither of them is necessary for following it.

- SCANSat adds maps and mapping sensors and has been used as the basis for the satellites. While this is helpful and nice for role-play you can just use a dummy satellite, such as that given in chapter 3.
- Procedural Fairings is a purely cosmetic mod in stock KSP. It allows you to make more streamlined vehicles but the parts can simply be omitted if you are not using it.


Follow With Manned Spacecraft And Stations

Even if you prefer 'stock' games I strongly recommend that you install and use the following mods. These are purely informational and do not change any parts so your craft and missions will be unaffected.

- Kerbal Engineer Redux (KER), MechJeb (MJ) and/or VOID – vital information you need for designing vehicles, such as TWR and deltaV stats. There is a lot of overlap in what these can display so you only need one of them. MJ is also an autopilot should you wish to use it for that.
- Kerbal Alarm Clock (KAC) - lets you set alarms for various events so you don't miss them. Not very important when you're starting but gets more and more useful when you have several vehicles in flight at the same time. By the time you have several interplanetary missions en-route, various satellites being emplaced in different orbits and a couple of ships about to re-enter the atmosphere it can be all too easy to forget when a manoeuvre is due.
- Navyfish's Docking Alignment or NavBallDockingAlignmentIndicator - docking can be needlessly tricky in some circumstances, especially when you're learning. Install one of these to make it easier; Navyfish's is better known and adds a docking window while the navball indicator, which is derived from it, is a simpler and more minimal tool.

Beyond those mods there are many, many more that you might like to consider. The following are some of the more popular that, however, will require you to change your game play:

- RemoteTech (RT) – if you like leading with unmanned missions this adds communications satellites. Note that while this is installed you will NOT be able to control unmanned vehicles while they are out of communications. Getting things right is therefore pretty important (which adds to the fun).
- Ferram Aerospace Research (FAR), Deadly Re-Entry Continued (DRE) – for added realism these change the aerodynamics of KSP quite considerably. You will need to redesign your craft and re-learn how to fly them in atmospheres with these installed. (DO NOT USE WITH THIS TUTORIAL).


Land On Planets And Moons

CHAPTER 2: PROJECT PROLOGUE

Starter rover, aeroplane and rocket. For learning the controls.

SECTION 1: PROJECT BRIEFING

Identity	Prologue – Starter Vehicles
Background	KSC has a set of vehicles with which new appointees are required to become familiar. Ground-crew must learn the centre's procedures for preparing, launching and recovering these. Engineers, flight controllers and crews must also learn their flight and performance characteristics.
Objectives	1) Find your way around KSC. 2) Understand vehicle construction in the VAB/SPH and launch/recovery. 3) Learn to control each of the vehicles.
Payloads	N/A
Vehicles	Rover – Mr. Kerman's Electrical Carriage Aeroplane – Trainer Mk1 Rocket – Rocket 1A.
Execution	Visit the SPH and VAB to examine the types of vehicle you can build and operate. Rovers are not very useful in general but provide a simple way to start learning the controls. Planes provide an efficient way to fly in atmosphere. Rockets are the easiest way into space.

Congratulations on your appointment to Kerbal Space Centre (KSC). The oversight committee have asked that before you begin new operations you follow the standard induction training and learn about the vehicles available to us. In driving the rover you will discover that KSC is quite a detailed setting, not just the game's main screen. The developers have included statues and … 'other things'. Flying an aeroplane allows you to go further and faster than driving a rover and, of course, is in three dimensions rather than two. Despite its low performance the Trainer Mk1 aircraft is a useful vehicle for short-range exploration so you may decide to use it for later missions as well. In contrast the Rocket 1A is completely useless in itself but learning to fly it is vital. The lessons here are just the main controls and instruments.

NB: This prologue is somewhat different to the later chapters as it is just preparation for the main campaign. In particular you are not expected to build the starter rover and aeroplane yourself; please use the pre-built ships from Dropbox, even if you intend to build the others. Start a new sandbox game in KSP and unzip the .craft files for these vehicles to your KSP\Saves\<save game name> folder. This prologue is also much more prescriptive than the later chapters so has a lot of 'do this', 'look at that' and not much explanation of how or why the vehicles were built as they were. Don't worry, when the real stuff starts it's much more informative – this is just to give you something to start from.

SECTION 2: MR. KERMAN'S ELECTRICAL CARRIAGE

Electrical Carriage At Monument

i) Data Sheet

Identity	Mr. Kerman's Electrical Carriage (the rover).
Purpose	Ground control familiarisation and local exploration.
Statistics	1.69t SPH/Dry, 25 parts, cost 6,534
Design	It's a box with electric-powered wheels, batteries and solar panels to keep them charged. Important points are the girders for a longer wheelbase and the ladder at the back.
Construction	Mk1 Lander Can, Cubic Octagonal Strut for Probodobodyne Okto 2 and Illuminator Mk1. 4 x M-Beam 200 I-Beam Pocket Edition with RoveMax Model M1 wheels. 2 x Z-100 Rechargeable Battery Packs. 10 x OX-STAT Photovoltaic panels. Telus-LV Bay Mobility enhancer.
Action Groups	Light/brakes – standard. Stage – deactivate Mk1 lander can torque. Gear – toggle ladder.
Performance	~20m/s, daylight only. Unsafe at any speed!

Announcing "Mr. Kerman is proud to present his ELECTRICAL CARRIAGE, a wheeled contrivance powered by KERBOL itself, which will be a PUBLIC CONVENIENCE for all discerning Kerbals" caused a certain misunderstanding of this rover's purpose but ensured its instant popularity. We've cleaned it out as well as we can but it still smells a bit. It also still demonstrates the main drawbacks of rovers – lack of power and a tendency to flip when turning and/or braking sharply.

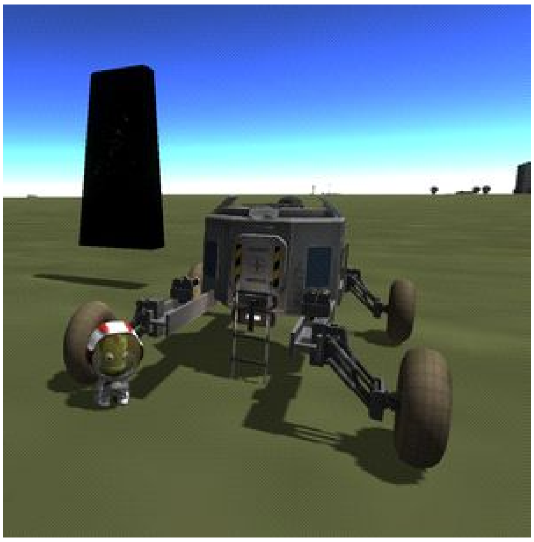
ii) Construction

Construction is first discussed properly in the Rocket 1A section and then at length throughout this tutorial. For now just have a look at the thing in the SPH and live with the notes below. (From the KSC screen click on the Spaceplane Hanger, click the Load button at the top-right of the screen, click Mr. Kerman's Electrical Carriage in the ship window, click the load button at the bottom of the window.)

iii) Staging And Action Groups

When you add lights and wheels to a vehicle KSP automatically assigns the appropriate action to the Light (U) and Brakes (B) action Groups. Similarly, when you add landing-gear/legs, KSP will assign them to the Gear (G) group. As there isn't any landing-gear on this rover I've used G for the ladder below the hatch on the back of the rover. Stage (spacebar) should be used when you start this vehicle to deactivate the reaction-wheel torque in the lander can. Keeping things simple at the moment, this is to minimise the problems it can cause while you're trying to turn. Check the action groups in the SPH. In the SPH and VAB screen, just to the left of the vehicle name, are three buttons - parts, action groups and crew. Click the action groups button to see and set them, click parts to go back to the 'normal' view.

iv) 'Flight'



Electrical Carriage At An Anomaly

MISSION 1: Driving

With the rover loaded in the SPH click the Launch button at the top-right of the screen (or click the runway from the KSC main screen and select the rover from the ships menu). Mr. Kerman's Electrical Carriage will be placed on the runway, KSP's physics engine take a second or two to kick-in and then you'll see the rover and camera 'settle' a little and it is ready for action.

Look at the navball at the bottom of your screen – the 'forward' direction is taken from the command pod orientation and is currently pointing straight into the sky. The Mk1 lander-can is upright and facing the right way but it's designed for rockets, not rovers, so KSP incorrectly assumes it will be going upwards. This means that your heading isn't the way you're facing and will wave all over the place as you cross slopes at different angles, making navigation difficult at best. For this reason the okto 2 at the top-front of the rover (it's what the headlight is attached to) is oriented forward properly. Right-click on it and select 'control from here' to align the navball to the horizon. Click the IVA button on your Kerbal's portrait at the bottom-right of the screen (or press 'C') to see the view from inside the lander-can. Press C again to return to the external view. Unfortunately the navball resets to the command-pod in IVA mode so you'll have to 'control from here' on the okto 2 again. In later designs, and especially when docking ships, which part you are controlling them from can become very important.

It is quite likely that the rover is rolling forward a little by this time (KSP does that) so press 'B' to activate the brakes action group and bring it to a stop. Now click on the Resources button at the top-right of the flight screen – it looks like a fuel-can – and check the electrical charge. If it's night-time this will be draining steadily but otherwise the solar panels should be keeping the batteries topped-up. Electricity is the only fuel/resource that the Electrical Carriage uses.

The Carriage is all in one piece so there are no 'stages' as such but press the spacebar to disable the reaction wheel in the lander-can. This has been set-up as an action group just because it's easier than right-clicking the parts each time you 'launch' the rover. Experiment with the camera modes (V) - Chase is probably best, with the camera behind the rover – and try out the light (U) and ladder (G).

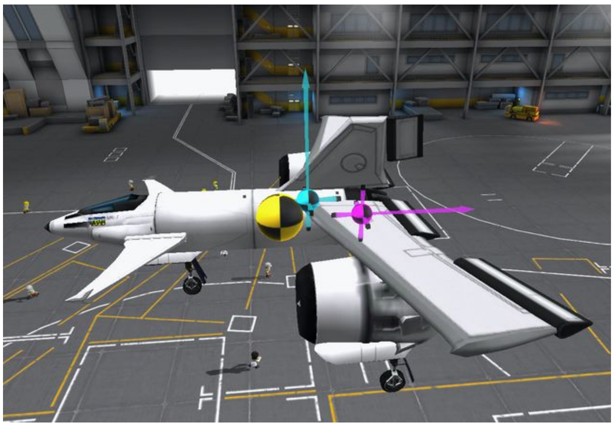
Drive around KSC and explore the buildings using the WASD keys. These correspond to pushing a joystick forward (W), back (S), left (A) and right (D); accelerating and steering the rover in the corresponding direction. You can slow down by 'accelerating' backwards or use the brakes (B). Squad have included quite a lot of detail in the KSC model that you'll otherwise never notice. Between the VAB and SPH, for instance, is a 'Mk1 memorial' statue. Be warned that steering too sharply at speed will cause the rover to roll over. Stop somewhere, extend the ladder (right-click on it and select that action or just press 'G') and 'EVA' your Kerbal. Kerbals on EVA use the same WASD keys <u>relative to the camera</u> and you will be prompted for other available actions, such as grabbing a ladder or re-boarding a pod. On a ladder you're more or less restricted to W=up/S=down relative to the Kerbal's head.

Once you've had enough, crashed or run out of electricity you can stop the 'flight' of the rover in any of three ways. First, come to a stop then move the mouse to the altimeter at the top of the screen. A green 'recover vessel' button will appear; clicking this removes the rover and takes you back to the KSC screen. The button does not appear if you are moving (the red 'abort' button which also appears is explained in the Trainer section). Second, click the blue 'space centre' button (or press 'esc'(ape) and select the 'space centre' button from the menu) to go back to the KSC screen but leave the rover where it is. Third, you can press escape and 'revert flight' from the menu and then select 'spaceplane hanger' or 'launch' to go back to that place *and time*. The passage of time will not be important at this stage but might be later on.

v) Notes

Things to note from this vehicle; rovers are relatively slow and have a tendency to roll or flip. Solar panels are vital on every vehicle, as are ladders if crew are present. Make sure you 'control from here' so the navball is pointing in the right direction every time you launch anything. WASD are the main controls for any craft. (To be completely honest, rovers aren't that slow – 20m/s is almost 45mph, which isn't bad for an off-road electrical vehicle light enough to be taken to the moons).

SECTION 3: TRAINER MK1



Trainer Mk1 In SPH

i) Data Sheet

Identity	Trainer Mk1
Purpose	Flight training and short-range exploration.
Statistics	3.504t SPH/3.1t dry, 25 parts, cost 16,191.
Design	The Trainer is designed to be cheap and easy to fly. It is useful for short-range exploration even after training. Stability was the priority, performance was not.
Construction	Mk1 cockpit, 2x structural fuselage, 1x basic jet engine. Tailfin and elevon 4, 2x advanced canards, swept wings, radial engine bodies, circular air intakes and fuel lines. 4 x elevon 1s, 3x small gear bays.
Action Groups	Gear, lights, brakes:standard, abort:shutdown engine, 1:jets, 5:ladder
Performance	Takeoff/Landing 30m/s, Ceiling 18km, max speed ~500m/s

ii) Construction

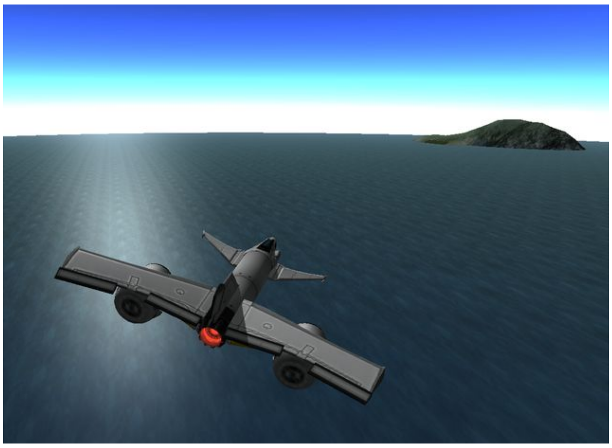
The manufacturer has not released details of the construction of this vehicle. No user-serviceable parts, warranty void if seal broken. KSC may develop its own planes in future but until then just use this vehicle 'as is'. (Plane construction is quite complex and will be discussed first in Chapter 4).

iii) Staging And Action Groups

Gear (G), lights (U) and Brakes (B) are all standard and assigned by KSP automatically. 'Abort' (backspace) is set to shut-down the engine. This can also be triggered by moving the mouse over the altimeter at the top of the flight screen and clicking the red 'abort' button that appears.

As an alternative to staging at start you may use Custom01 (1) to toggle the jet engine on and off. This becomes necessary for spaceplanes and Custom02 is reserved for them. Finally, as the Gear (G) group now has its proper use of raising/lowering the landing-gear the cockpit ladder function has been moved to Custom05 (5).

iv) Flight



Trainer Mk1 In Flight

Launch, wait for physics to start, apply brakes and set camera mode/position as for the rover (Chase mode with the camera behind and slightly above the plane is probably easiest). The cockpit already faces 'forward' as you'd expect so there is no need to 'control from here' on any part.

The main control keys remain WASD plus Q/E for roll left/right. Aircraft usually use roll instead of – or at least much more than – the yaw controls A/D. To turn left or right you roll in that direction and 'pull back on the stick' (S) to pitch the nose 'up' in that direction. The controls work in one of two modes – coarse and fine, which are toggled using the Caps-Lock key. In fine mode the pitch/roll/yaw indicators at the bottom-left of the screen change from red to blue and give you much better control of the aircraft. You are strongly advised to use fine controls whenever flying a plane. Fine is less useful for rovers and rockets but you may want it when performing more delicate manoeuvres such as docking.

You should also become familiar with the trim controls if you will be flying aircraft much. Trim is used to adjust the 'natural' pitch/roll/yaw of the plane so you don't have to use the main controls to correct it as much. You adjust trim using the same control-keys but holding the 'mod'(ifier) key (not to be confused with installable game mods) at the same time. On Windows 'mod' is the 'alt' key so alt-S, for instance, will increase the pitch trim of the plane, increasing its tendency to nose-up on its own. Exactly how trim should be set depends on each aircraft, its speed, throttle and fuel-load at any time.

MISSION 2: First Flight

KSP defaults to 'launch' with 50% throttle (don't ask me why) and this 'plane will fly well at that setting. With the camera and fine controls set, just activate the engine (spacebar=stage or 1=toggle engines) for take-off. Jets take time to 'spool up' to full power so in real life pilots 'hold the plane on the brakes' to prevent it rolling down the runway at low speed. With the trainer you don't have to worry about that but you will want to for heavier aircraft.

At any speed above about 30m/s rotate ("pull back on the stick", S) to 20-degrees and the plane will climb. Retract the landing gear (G). **Use short key taps/presses** as planes are very sensitive to controls. Try to maintain a nose-up pitch of about 10 – 20 degrees. To counteract the nose-down tendency adjust trim-up (alt-S), when you get it right (about one 'tick' above centre on the lower-left indicators) the plane will more or less fly wherever you point it, without WASD correction. BY DESIGN it is harder to control the trainer without adjusting trim. Fly around – you have plenty of fuel for practice. Do not exceed the operational ceiling and try to avoid hitting the ground or buildings! It's probably best to press escape and 'revert to spaceplane hanger' or launch rather than trying to land on your first flight.

MechJeb (MJ): If you are using this mod make sure it's not set to 'limit to terminal velocity' in its Utilities window, otherwise you may find it switching-off your engine at awkward moments.

MISSION 3: Circuits & Bumps

Real pilots spend an awful lot of time on 'circuits & bumps' - taking off, flying a circuit around the runway, lining-up for landing and 'bumping' down before immediately lifting off and doing the whole thing again. A standard procedure is: take-off and climb to 2-6km on heading 090 (East, 90 degrees, the direction the runway faces). Level-off and turn to 0 (North) then 270 (West) degrees. Fly past the runway and continue for ~20km; half-way to the mountains. Turn left to 180 (South) and then back to 90 degrees, reduce throttle (left ctrl-key) to 30% and line-up on the runway. Descend to ~1km at 10km from the runway and 100m down each kilometre closer (so 500m at 5km, etc.). Reduce throttle to just one or two 'ticks' on the navball gauge about 2km from the runway and control descent-rate using pitch and trim as speed decreases. 'Flare' (pitch-up more) to reduce speed and descent rate just before touch-down near the start of the runway, landing at under 100m/s horizontal speed and -10m/s vertical. For bumps immediately put the throttle back to half or more and go around again. It's relatively easy with this plane and practice works for larger/faster ones; don't forget you can pause or revert the flight (escape key) whenever you want. Don't worry too much about landing on the runway, any flatish space will do and there's plenty of it North of KSC. Also try circuits to the right instead of left and just generally exploring when you have the confidence.

(Space)planes are something of a specialism in KSP – some people use them all the time and some people never do. This tutorial includes them as a significant and useful aspect of KSP but it is up to you whether you want to spend much time learning to fly them at this stage. Rockets are a lot easier in many ways and this is a space simulator, after all.

v) Notes

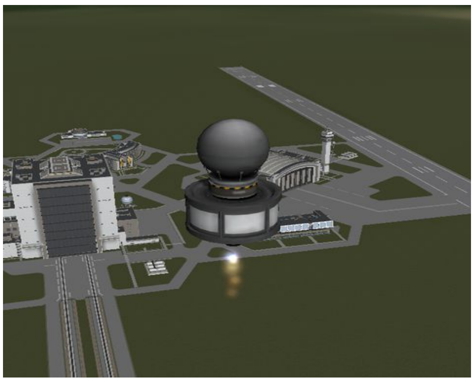
In 3-dimensional flight the pitch controls (W/S) move the nose down/up instead of forward/back as they do in a rover. Correct use of trim (alt-WASDQE) makes all the difference between a stable and unstable aircraft. Above their operational ceiling jets will run out of air and 'flameout' - re-igniting when you fall (or throttle) back enough that there is sufficient air again. This is not much of a problem in the trainer but in a high-performance multi-engine spaceplane can easily put you into an unrecoverable spin.

SECTION 4: PROJECT ADDENDUM (Easter Egg Spoiler)

Identity	Prologue Addendum 1 – KSC Anomaly
Background	Test pilots have reported 'something' on the ground North of KSC. The oversight committee request, but do not require, that you send someone to investigate this.
Objectives	Locate and identify the anomaly North-east of the start of the runway.
Payloads	N/A
Vehicles	Mr. Kerman's Electrical Carriage and/or Trainer Mk1
Execution	Use either or both the vehicles with which you have trained to find and identify whatever is out there, if anything. This is a photo opportunity more than anything else so skip it if you wish.

'Easter Eggs' are things the developers have put into the game 'for fun' (programmers get bored at work too). It is part of the structure of the campaign in this tutorial that the SCANSat satellites, while mapping, will reveal the location of these Easter Eggs – SCANSat reports them as 'anomalies'.

SECTION 5: ROCKET 1A



Rocket 1A Launch

i) Data Sheet

Identity	Rocket 1A
Purpose	Construction and rocketry training.
Statistics	0.763t VAB/0.262 dry, 4 parts, cost 1,450
Design	The Mk1 is our first functional rocket prototype and uses very few, simple, parts.
Construction	Stayputnik Mk1, small inline reaction wheel, FL-T100, Rocomax 48-7S.
Action Groups	abort, 3:rocket
Performance	(Kerbin) TWR 4.01, 3,665m/s deltaV.

ii) Construction

In memory of the Sputnik satellite (not that Kerbals have ever heard of it, of course) we start with a Stayputnik Mk1 pod to control our first space-capable vehicle. This is a rocket, built in the VAB and launched from the pad, not the SPH and runway as the rover and plane are. For stability there is an inline reaction wheel beneath this.

Early tests with our smallest engines – the LV-1 and LV-1R – showed that they were under-powered for the amount of fuel needed to reach space. Upgrading to the 48-7S we have had much greater success. Reports from the onboard computer (KER/MJ/VOID deltaV stats if you're using these mods) indicate that with an Fl-T100 fuel tank (45 units liquid fuel and 55 oxidiser) this gives a TWR of 4.01 and deltaV of 3,665m/s, although we have no idea what that means yet. Bob's gone to get a book so we can find out but we think it'll get to space.

It is very simple to build this yourself. Exit from the SPH if you are still there then click on the VAB in the KSC screen. Every vehicle needs a manned pod or probe core to control it so start with the Stayputnik Mk1 by clicking on it in the 'pods' tab of the parts list. From 'command and control' select and add a small inline reaction wheel. Switch to the 'fuel tanks' tab and add an FL-T100 fuel tank below the Stayputnik and a Rocomax 48-7S engine, from the 'engines' tab, below the fuel tank. Pretty simple rocket, but it works. To see the performance figures add a (KER) ER-7500 computer flight unit from the 'science' tab or (MJ) MechJeb 2 (AR202 case) from the 'control' tab, depending on the mod(s) you are using. There is no way to see these figures in the game without mods and they are vital to rocket design.

****Save the vehicle once you've built it****

NB: as explained in 'flight' below it is a good idea to put KER/MJ or some other very light object on the front of the rocket so you can tell which way around it is later.

iii) Staging And Action Groups

Abort shuts-down the engine while Custom03 (3) toggles it on and off. It's a good habit to always provide some 'abort' safety action. The engine toggle is pretty redundant but is compatible with later vehicles.

iv) Flight

From the VAB click 'Launch' or, from the KSC screen, click the launch-pad and select the Rocket 1A from the vehicles menu. As with the other vehicles wait for the physics engine to kick-in, then press 'T' to engage SAS when you see the rocket and camera settle a little. SAS is a stability aid, making use of specific SAS units, inline reaction wheels and the torque provided by most manned pods, that attempts to keep a fixed heading when active or speeds-up the turn rate when not. It can be important for rockets as some of them will tend to fall over on the pad without it.

The navball will be pointing straight up into the sky, as it did on the rover, but this time that really is the 'forward' direction we want. As with the plane, the primary flight controls are WASDQE and you can toggle coarse/fine with Caps-Lock (you shouldn't need to with this). Looking at a rocket on the pad the yaw and roll left/right keys (A/D, Q/E) work as you'd expect with 'forward' being towards the top of the rocket. The pitch controls (W/S) can be a little confusing, however, because there is no obvious 'up/top' - as opposed to 'forward' - direction, so what do 'pitch up' (S) and 'pitch down' (W) mean? To understand rocket pitch you have to know that the 'top' of the command pod/probe core is the side which faces right in the VAB when it is first placed, towards you as it appears on the pad. It's easier to see in the SPH as they are placed right-side-up but rockets are expected to launch standing on end so things are different in the VAB. For this reason it is a good idea to put something light – like KER or MJ – on that side so you can see where it is in-flight. Alternatively, and more flexibly, get used to using the navball, where the nose indicator is always the right way up and is the ideal way to navigate in space rather than looking at the rocket itself.

MISSION 4: Up Like A Rocket

Throttle to max (left shift-key/Z) and press space to go there – space, that is. Watch the rocket, watch the altimeter, watch the Vertical Speed Indicator (VSI, thing to the right of the altimeter), watch the navball and its speed reading. Enjoy the view, especially of the rocket between 7km-26km. When the fuel runs out the rocket will continue upwards a long way. When it starts to fall again (VSI points below horizontal) press F3 for a flight report and check the maximum altitude it reached. If it's above 69km, congratulations – you've made it into space! Close the flight report and press escape then revert the flight to launch or, if you're so inclined, watch the thing smash into the ground and destroy itself then prepare another one for launch.

MISSION 5: Up Like A Wobbly Rocket

After launching, as above, disengage SAS (T) and use the control keys (WASDQE) to steer the rocket. Getting into orbit not only means getting high enough to escape the atmosphere (70km) but also going horizontally fast enough to stay there. The most efficient way to do this is to gradually turn from straight-up on the pad to a heading of 90 degrees and pointing at the horizon around 40km. Don't worry about it too much at the moment, especially as the Rocket 1A can't get into orbit anyway (until mission 7), just get the feel of the controls.

MISSION 6: Slow But Sure

In your first couple of flights you should have seen white, then red, atmospheric effects around your rocket as it got faster and faster. This is the same thing that causes burning-up on re-entry and, simply, means you're going too fast. Specifically, you're going faster than 'terminal velocity', wasting a lot of energy to atmospheric drag and compressing the air itself so much that it is heating up and, eventually, getting to the point of plasma. That sort of thing can kill your rockets and crews and even if it doesn't that wasted energy means fuel you can't use later, in space. Drag means it isn't worth going any faster than terminal velocity but that velocity itself increases as you go higher and the atmosphere gets thinner – there's less of it to push yourself through. The best ascent profile accelerates very quickly at full throttle to terminal velocity then throttles-back to 'only' accelerate at the same speed terminal velocity is increasing. Beyond about 15km your rockets won't be able to keep up with this increase anyway so you can go full-throttle again without wasting fuel. The first balancing act of getting into space is that if you go too slowly gravity wins and you waste fuel to lift, if you go too quickly the atmosphere wins and you waste fuel to drag.

Have another flight with the Rocket 1A, leave SAS engaged as in the first flight, but this time reduce to half-throttle at about 400m (altimeter at the top of the screen) and put it back to max at 15km. Get another flight report (F3) and compare your maximum height to the first flight. My figures are roughly 148km for the first and 234km for this – quite a big improvement and no danger of burning-up (which doesn't happen in stock KSP anyway, so don't worry).

The only trouble with all this is that the sky is not notable for its speed-limit signs. KER/MJ/VOID can tell you when you're going too fast but otherwise you'll just have to check and test your designs/throttle against atmospheric effects and the terminal velocity figures for various altitudes (see the wiki and other places). Also note that MJ is an auto-pilot and amongst its Utilities settings is 'limit to terminal velocity'. If you enable this MJ will automatically control your throttle for you and, for instance, will reduce then gradually increase it as you get higher rather than just going flat out at 17km. MJ's about 5% better than my simple instructions above – with a maximum altitude of 244km – but some people think using an auto-pilot is 'cheating' (I don't).

MISSION 7: Orbit

Rocket 1B In Space

So far the rocket has gone up and come more-or-less straight back down. Getting into orbit, so you stay in space, means going horizontally fast enough that you keep missing the ground as you 'free fall' towards it. The ideal 'low' orbit around Kerbin is generally taken as 75km; space starts at 70km, the extra is a safety-margin. As it is the Rocket 1A does not have enough fuel to establish orbit so go back to the VAB and give it a bigger fuel tank (FL-T200 instead of FL-T100 – save it as Rocket 1B). Note that the 'wrong' way to get to orbit is to go straight up and then turn to go sideways. Instead, as briefly mentioned before, you should gradually turn from straight-up to pointing at the horizon as you climb. The standard ascent instructions given to KSP beginners is "*go straight up to 10km, yaw right (D) to 45 degrees pitch (from 90=straight up). Switch to map mode (M) and when your apoapsis reaches 50km yaw further right to reduce pitch to 20 degrees. When your apoapsis reaches 75km cut the throttle (X), create a manoeuvre node at apoapsis to bring your periapsis above 70km, coast to the node and burn into orbit.*"

...You probably want to read some 'getting into orbit' tutorials at this point...

There is, as you will see, an awful lot to do and not much time in which to do it. With practice you'll get better at "gravity turns", using the manoeuvre-node editor, setting the node, turning to the navball indicator and timing the burn. Once you are reasonably confident that you can orbit you're ready for the first real projects of this tutorial. Oh yes! The real thing hasn't even started yet.

(MJ, being an autopilot, can fly to orbit for you and much more. It's worth the effort learning to do it yourself though and only using MJ when the routine of many launches starts to get tedious. It's all up to you though, don't let anyone tell you "you're having fun the wrong way" if you decide to use it as a matter of course.)

v) Notes

It's easy to get into space, harder to get into orbit. Orbit means getting high enough and going sideways fast enough that your periapsis (low point of orbit) is over 70km, preferably 75km. You can't, efficiently, go faster than terminal velocity so may need to throttle-back at lower altitudes and throttle-up as you get higher. NB: the throttle-settings depend entirely on the performance of each craft and those given here are specific to the Rocket 1A/B; don't expect them to work with other vehicles. The best way to get horizontal orbital speed is to perform a "gravity turn" during your "ascent burn". Remember to disengage and re-engage SAS before/after each manoeuvre. Once your apoapsis reaches the desired altitude cut throttle, coast to Ap, then do an "injection burn" to increase your periapsis to orbital height as well. Cut engine again, wipe the sweat from your brow and breathe. Enjoy the view and sense of achievement – getting into orbit for the first few times is quite an achievement.

It's also just the start.

CHAPTER 3: PROJECT FOOTSTEPS

Orbital Satellites. Staging, tweaking, orbital manoeuvres.

SECTION 1: PROJECT BRIEFING

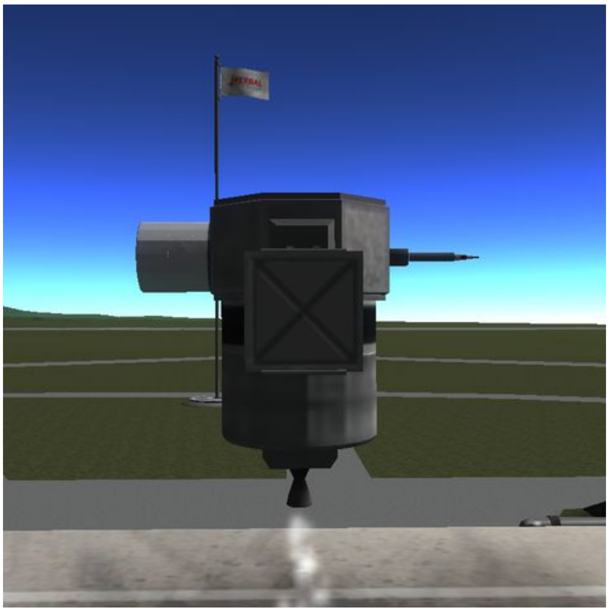
Identity	Project Footsteps – Mapping Kerbin
Background	Now that KSC has the ability to reach orbit we have been tasked with mapping the surface of Kerbin to provide drivers and pilots with accurate navigation information. The scanning instruments themselves have been developed by the Scientific Committee of Advanced Navigation (SCAN) and consist of low-, mid- and high- orbit sensors.
Objectives	1) Build a dummy satellite equipped with non-SCAN scientific instruments. This will be used when the SCAN equipment is not available. Ensure that the instruments you use are the same total mass as the SCAN ones so they can swapped-out as required. 2) Build variants of this satellite each carrying one of the low, mid or high SCAN sensors. 3) Build launch vehicles for each of these variant satellites. 4) Place one each of the satellites in orbit.
Payloads	SCANSat Low, Mid and High (or Placebo for all three if SCANSat is unavailable).
Vehicles	Two-step, Sidestep and Quickstep.
Execution	Unlike Rocket 1A/B 'the rocket' is not the mission – getting the satellites into the right orbits is. Usual design practice is to treat 'the payload', which has a job to do in space, as completely separate from 'the launch vehicle' (rocket) which gets it there. It is best to design the satellite payloads first then, when you design the launch vehicles, the only things you have to worry about are how much the payload masses and where you have to put it. It would be possible to design and use only the largest launch vehicle for all three satellites but the oversight committee have rejected this in favour of three different vehicles. Starting with the smallest and simplest and gradually building-up will enable KSC to gain early, and cheap, experience before working with bigger payloads and harder objectives.

Start small, otherwise you can easily get frustrated. Small vehicles are usually easier to design, build and fly. Easier missions with easier ships mean you're more likely to succeed, feel good and progress. In KSP failure and explosions can be fun but the chances are you'll have those anyway. Don't tempt the Kraken by trying too much too soon.

One of the famous quotations used a fair amount on the KSP forums comes from the science-fiction author Robert A. Heinlein's "Get to low-Earth orbit and you're halfway to anywhere in the solar system." If you have followed the Prologue in the previous chapter or otherwise got the skills to get to orbit you also have half or more of the skills needed to get anywhere in the Kerbol system. This chapter will give you the rest, at least in outline.

The launch vehicles in this chapter are somewhat contrived in order to demonstrate different staging strategies, solid-rocket boosters and 'tweaking'. This is especially true of the second design (Sidestep) but, in any case, you will not be launching such light loads again in this tutorial. Also note that they are over-powered to allow for those readers wishing to use Procedural Fairings for streamlining (which adds mass) or more instruments.

SECTION 2: SCANSATS PLACEBO, LOW, MID & HIGH



SCANSat Placebo Payload

i) Data Sheet

Identity	SCANSat Placebo/Low/Mid/High
Purpose	Orbital surface-mapping
Statistics	0.236t VAB/0.172 dry, 6 (7) parts, cost from 3,120/5,220/10,720/26,720
Design	Less is more – as long as it works
Construction	Okto, Z-200 battery, Oscar-B fuel tank, LV-1 engine, OX-4L solar panels, instrument(s)
Action Groups	abort:shutdown engine, 6:engine, 7:instrs, 8:solar panels
Performance	(Kerbin) TWR 1.73, 894m/s

ii) Construction

These satellites don't have to *get* to space, just work when they're there, which simplifies their design a lot. They will need to have a probe core and carry a SCANSat sensor or other instrument(s) of the same mass and in a lot of ways this is the only payload. For these to function, however, they will need electricity. You can get that with solar panels in sunlight but on the night side of the planet a battery will be necessary and the solar panels will also have to charge this. In practice it is almost impossible to establish and maintain a perfect orbit so some form of propulsion for orbital adjustment and station-keeping is important, even more so in real life. The smallest, lightest fuel tank and engine in KSP are plenty for such small satellites as these – you'll use the fuel in short bursts, if at all; first to fine-tune the orbit and then at long intervals to maintain it.

At launch a complete satellite will form the payload for the launch-vehicle and the more it carries (specifically, the higher its mass) the more powerful and therefore bigger and complex the launch-vehicle will need to be. As a rule of thumb rockets may only be 10% efficient – meaning 100kg added to the payload results in 1 tonne added to the total launch. With decent design this 10% 'payload ratio' may easily be increased to 15% and good designs can reach 18-20% but that still means even a small increase in the payload has a big knock-on effect. The lightest probe core is the Okto 2, but the heavier Okto includes a reaction wheel, so that's what we go for. Similarly the Oscar-B fuel tank and LV-1 engines are the lightest. Each SCANSat sensor masses the same (0.03t). As a compromise between minimum-mass and maximum-functionality the satellite design given uses the slightly heavier Z-200 battery instead of a Z-100 and OX-4L solar panels. Planning ahead – how long will a satellite spend on the night side of Eeloo? How much power will it use during that time? Will the solar panels be able to power it and recharge the battery during the daylight transit, so far from the sun? This is a tutorial not a walk-through so you'll have to find those things out for yourself.

Instrument particulars: For 'placebo' the pictures illustrate an instrument-payload of one Communotron 88-88 and one Communotron 16. Any other object(s) that mass 0.03t – to match with a single SCANSat instrument – may be used instead, if you wish. The SCANSat orbital-sensors themselves are found on the 'science' tab in the VAB/SPH, if you have installed the mod. The 'low' satellite needs to be equipped with a SCAN RADAR altimetry sensor (5-500km, optimal 5km), 'mid' with a SCAN multispectral sensor (5-500km, optimal 250km) and 'high' with a SCAN SAR altimetry sensor (5-800km, optimal 750km).

iii) Staging And Action Groups

Separate groups have been assigned to toggle the engine, instrument(s) and solar panels. The instruments and solar-panels should always be operating in space but can't be deployed in the atmosphere, during launch, or the drag will rip them off and destroy them. Their operation could be combined into one group but if power is nearly exhausted it may be necessary to turn off the power-consuming sensor while keeping the power-generating panels deployed. It is also a good idea to disable the engines on every vehicle except when using them; at least if you are as ham-fisted as me and make a habit of pressing left-shift at the wrong times, thereby throttling-up and sending the craft off to an unintended destination/death. When assigning action-groups you will save a lot of sanity if you try to standardise the numbers that you use. Throughout this campaign (and almost everything else I do) groups 1-5 are for the vehicles that deliver payloads, 6-8 for the payloads themselves and 9-10 for space-stations/bases. Experiment to find a convention that works for you, otherwise you'll find yourself switching between craft, forgetting the action-groups and (de)activating the wrong things at the wrong time.

Abort should always turn off engines, and/or take more useful emergency escape action.

iv) Flight

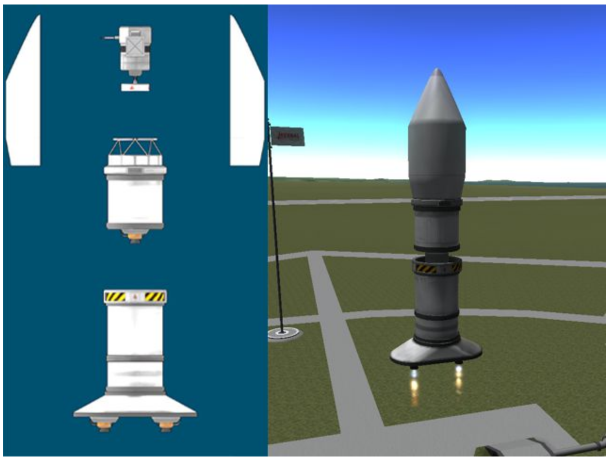
SCANSat Placebo Over Kerbin

These satellites are dependent on their launch vehicles to get into space. Flights are therefore detailed below.

v) Notes

Very often less really is more in space-vehicle design, don't carry anything you don't need to. Especially when you're starting. Design payloads first and work 'backwards' through their mission, adding extra components only as needed. A little more payload mass means a lot more launch complexity.

SECTION 3: TWO-STEP



Two-Step + SCANSat Low Launch

i) Data Sheet

Identity	Two-step – Launch Vehicle
Purpose	Placing a SCANSat satellite in a 75km Kerbin polar orbit
Statistics	(inc. Placebo) 4.176t VAB/1.113 dry, 16 parts, cost 8,645
Design	2 serial-staged with dual-engine first stage
Construction	TR-2V decoupler, (Procedural Fairings - fairings base, fairings), RC-001S RGU. FL-T200 fuel tank, 48-7S engine. TR-18A decoupler, FL-T400 fuel tank, TVR-200 bi-coupler, 2x48-7S engines.
Action Groups	abort:shutdown engines, 3:rockets, (4:fairings)
Performance	(Kerbin) TWR 1.46, 6,593m/s

ii) Construction

Two-Step + SCANSat Low 2nd Stage

Working backwards we start with a SCANSat satellite as the payload. This will need to separate from the launch-vehicle once in orbit so a TR-2V stack decoupler (structural tab) goes underneath it. If you are using the Procedural Fairings mod for streamlining (aerodynamic parts tab) add a 1.25m fairing base under the decoupler and, with symmetry 2, enclose the payload in egg-shaped or conic fairings. In order not to leave debris in space (a best practice) the last stage of a launch vehicle should be able to de-orbit itself after separating from its payload. That means it must be an independent vehicle in its own right, however briefly, and will need a probe core. The RC-001S remote guidance unit (RGU) is used here to fit with the fuel-tank size.

It's now time to start looking at performance figures; TWR (Thrust to Weight Ratio) is an easy concept. TWR is how much harder your engines can push (thrust) up than your mass (weight) is dragging you down. With a TWR lower than 1 your engines can't even lift the rocket off the ground and you aren't going to space today. At exactly 1 you can hover or maintain any speed you already have but can't accelerate away. Obviously then you need a TWR higher than 1 to take-off but less obviously you also don't want a TWR that is too high, because that would make you accelerate too quickly and exceed terminal velocity (see mission 6 in the previous chapter). In stock KSP an ideal launch TWR is considered to be between around 1.4-2. Putting the same FL-T200 fuel tank and 48-7S engine as used on the Rocket 1A under the RGU gives a TWR of 1.78, which is almost perfect. Another FL-T200 tank, however, adds so much mass that the TWR drops to 1.08, which is too low for comfort – stay with the FL-T200/48-7S combination. You can increase the TWR of a rocket by removing excess mass or by adding extra/more powerful engines.

DeltaV is a slightly more difficult concept; it is the amount by which you can change your velocity vector; usually measured in metres per second (m/s). This is a speed, like mph, but as a 'vector' it also has a direction – simply put, if you are going 'at 80mph' you must be going in some particular direction. From stopped and with a deltaV of 1,000m/s you could accelerate to 1,000m/s West or 1,000m/s Up, etc. Stopping and turning are the same – accelerating to 500m/s East and then slowing down to 0m/s again would also take 1,000m/s. Likewise, you could accelerate to 500m/s North then turn and accelerate 500m/s East, with a resultant velocity vector being the North-east diagonal you'd get if you draw a '500' line up and another across on a piece of paper (a bit over 707.1m/s). The amount of deltaV a rocket has mainly depends on the amount of fuel it has and how efficient its engines are at using that fuel – the engine's Isp, shown in the VAB/SPH. Like TWR it also depends on the vehicle's mass – a heavier vehicle will be harder to push than a lighter one.

In summary then, in KSP, engines burn a particular amount of fuel per second to produce a certain amount of thrust. Their thrust must be enough to lift the mass of the rocket with a reasonable acceleration. Depending on how much fuel the engines have and their efficiency that thrust will be able to change the rocket's speed and direction by a certain amount, less if it is heavier. NB: Stock KSP does not show you these figures. You will either have to work them out by hand every time you make a change to a rocket or use KER/MJ/VOID to display them.

Back to the Two-step launch vehicle: we have a rocket with an FL-T200 fuel tank and 48-7S engine giving a TWR of 1.94 and deltaV of 3,459m/s. While the TWR is fine we need at least 4,500m/s deltaV to reach orbit (remember this figure!). In particular, for this our first useful rocket, we want to add some margin for error and de-orbit fuel and would ideally like >5,000m/s deltaV. If we add fuel to increase the deltaV the TWR drops to an unacceptable level so what we have to do is add another 'stage' to the rocket – in effect, build a rocket to lift the rocket. Add a TR-18A stack decoupler under the engine, then an FL-T400 fuel tank. This is all much too heavy for a single 48-7S engine to lift but two can; add a TVR-200 stack bi-coupler and two 48-7S engines. This gives a TWR of 1.46 and deltaV of 6,593m/s, as shown in the data sheet. The rocket is a little under-powered at launch (TWR low) but has plenty of fuel (deltaV high). The bottom two engines will launch the rocket, burning through the 180 units of fuel in the FL-T400 tank. When that is empty we will activate the TR-18A decoupler, dropping the now useless engines and tank, and use the 'upper stage' FL-T200/48-7S to complete the launch into orbit. Once in orbit this upper stage will also be jettisoned and the payload is free to continue its mission. Note that however we build the lower stage(s) and whatever they do the stage(s) above them remain complete and intact, just as they were originally designed.

Ideally Two-step would have an extra, or more powerful, engine on the bottom stage but this design is sufficient to illustrate a classic, 2 serial stage, strategy for rocket construction. Rocket 1A was simpler, being Single Stage To Orbit (SSTO) but such designs are usually not efficient or even possible – there has never been a real-world SSTO. Splitting the mass between two or three stages, typically serial-staged like this design, improves efficiency and is the way nearly all Earth rockets are launched.

iii) Staging And Action Groups

The two lowest engines must be set in the VAB to the first stage to fire at launch (stage 3 if using procedural fairings, stage 2 otherwise). The stage above/after that has the TR-18A decoupler and upper 48-7S engine. The procedural fairings are jettisoned in the next stage (if you are using them) and, finally, the top/last stage activates the small TR-2V decoupler and the satellite's LV-1 engine.

As with all vehicles the 'abort' action group will shutdown the engines. We have no idea when/if this will be used so ALL the engines should go in here. Action group 3 is used to toggle the launch-vehicle rockets but not the satellite's, which has already been assigned to group 6. Finally, if you are using them, the streamlined fairings should be jettisoned once the vehicle leaves the atmosphere and before the orbital circularisation burn, so they aren't left in space as debris. They are therefore assigned to action group 4 in this design.

Quite a lot of action groups are being defined now. As I have mentioned, I try to maintain a single convention for them just so I don't forget which does what. This convention will be followed throughout this tutorial but you will probably want to experiment with your own – whatever works for you is best.

- Stage, RCS, SAS – generally not used
- Gear, Light, Brakes – automatic KSP assignments + parachutes
- **Abort – shutdown all engines, other 'escape' options**
- Custom01 – Launch Vehicle: jets
- Custom02 – Launch Vehicle: intakes
- **Custom03 – Launch Vehicle: rockets**
- **Custom04 – Transfer Vehicle: enter orbit**
- Custom05 – Transfer Vehicle: operations
- **Custom06 – Payload: engines**
- **Custom07 – Payload: instruments**
- **Custom08 – Payload: solar panels**
- Custom09 – Stations: Engines
- Custom00 – Stations: Instruments

iv) Flight

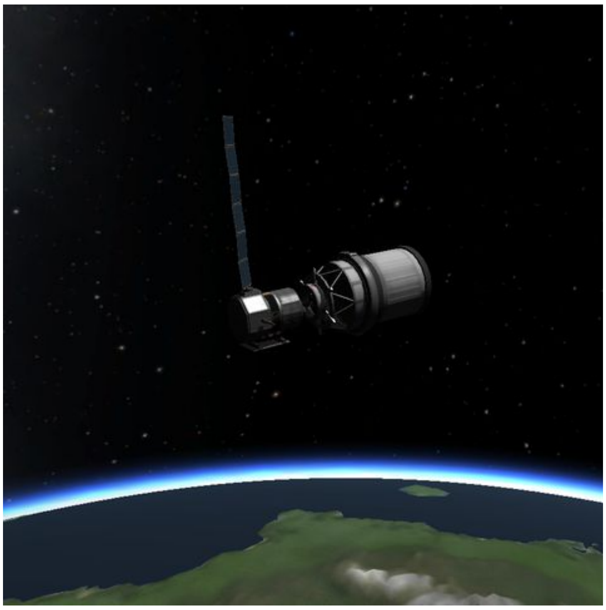
Normal launches, as you will have learnt, use a gravity turn to the East for efficiency, resulting in an equatorial orbit. That won't do for the SCANSat satellites though because they would be going over and mapping the same 'strip' of ground around the equator again and again. Instead they need to be placed in a *polar* orbit – crossing the North and

South poles. As they orbit the world turns beneath them, presenting a new strip of ground on each pass. Over several orbits these strips add up to give us a complete map of the surface. The optimal height for the SCANSat altimetry sensor, as fitted on the SCANSat Low satellite is 5km. This is not a viable orbital height around Kerbin as it is deep within the atmosphere, so our first mapping mission will be put into a 75km orbit; as low as possible while still being outside the atmosphere. It is still well within the operating range of 5-500km.

MISSION 8: 75km Polar Orbit

Move Two-step to the launch pad by clicking 'launch' on the VAB screen or clicking the launch-pad from the KSC screen and selecting it from the vehicle menu. Once the physics engine has engaged press 'T' to engage SAS. Throttle to max and press the spacebar to launch. From now on this sequence will be assumed and not repeated for every launch. Follow your preferred ascent-profile but do your gravity turn to the North (pitch down, W) instead of East. Press the spacebar again to stage – jettison the tank/engines – when the first stage is exhausted between 14km and 16km. An 'advantage' of the under-powered first stage on Two-step is that you won't have to worry about throttling-back at terminal velocity, you can just keep full throttle all the way. The upper 48-7S will immediately take over when the lower stage is jettisoned. Cut engine as normal when your apoapsis reaches 75km, set your 'circularisation burn' manoeuvre node and then stage again to jettison the fairings when you leave the atmosphere (69/70km). As these are jettisoned before the circularisation burn is carried out they will fall back into the atmosphere like the first rocket stage and be destroyed without leaving any debris.

We also need to ensure that the vehicle does not run out of electricity at any point. We will use the payload solar-panel for this as it will not detract from the satellite's functionality later. Consumables (fuel) on a payload should not be touched at all but solar panels won't be used up so it is 'ok' to make use of them. It is not best-practice to rely on anything from another vehicle/payload though – a launch vehicle *should* be designed to work with any payload within its lifting-capability and such a payload might not have solar panels at all. In this case it's 'ok' because Two-step is specifically designed for the SCANSat Low satellite. Once the fairings have been jettisoned deploy the solar panels (action group 8).



Two-Step + SCANSat Low Fairings Jettisoned

Carry-out your circularisation burn at apoapsis and check your orbit figures – apoapsis (Ap), periapsis (Pe) and inclination (from 0 degrees = equatorial orbit). These can be seen in the map mode (M) or using KER/MJ/VOID. Map mode will show you the apoapsis and periapsis figures directly but not the inclination. You can get around this by clicking Mun and 'set as target'. Since Mun's orbit is at 0 degrees relative to Kerbin the difference shown at the Ascending and Descending Nodes (AN/DN) of your orbit is also your inclination (it really is a lot easier to use an information mod). If you did your gravity turn directly to the North your orbit will end-up passing East of the pole and the inclination will be less than 90 degrees – why? For an 'ideal' orbit we want Ap and Pe to be equal (a circular orbit) and the inclination to be 90 degrees. If you've got such a perfect orbit; stop showing off! It's unlikely that you have though so we will use the satellite's ability to manoeuvre to improve it. Return to flight mode by pressing M again.

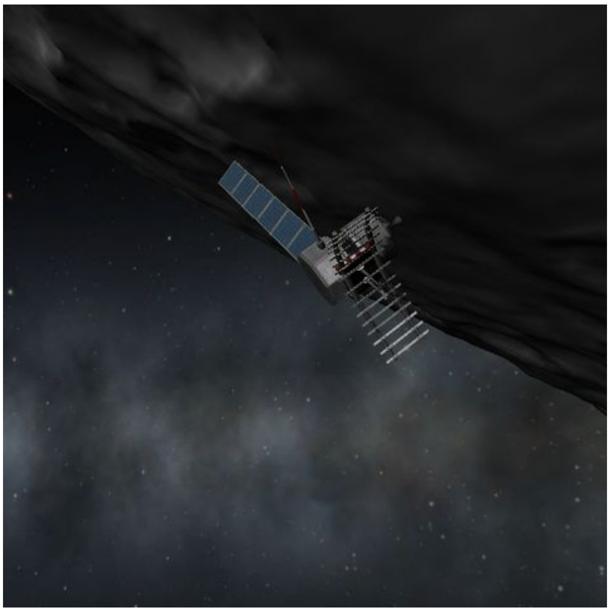
Before the satellite can adjust its orbit we need to separate it from the last stage of the Two-step launch vehicle and, to avoid leaving debris, de-orbit those remains. Stage again to separate the satellite and use '[' or ']' to switch between vehicles. The satellite should be fine for the moment because it has the solar panel but now Two-step is running on the residual charge left in its probe core. Before this expires turn the vehicle so it is facing retrograde on the navball and throttle-up to burn all the remaining fuel and push it back into the atmosphere. Cut engines (X) when the fuel is used up or KSP will still think you're "under acceleration" and not let you switch to another vehicle.

You won't be able to switch back to the satellite with '['/']' because it'll be too far away. Change to map mode again and you'll see Two-step's orbit-line in blue, hitting the surface, and the SCANSat Low satellite's orbit-line in white and going completely around the planet unless you've done something wrong. Click on and 'switch to' the satellite in order to take control of it again. Now use its engine and fuel to make the orbit as circular as you can (equal Ap and Pe) and with an inclination of 90 degrees. You will probably need to do several, small, adjustments at Ap, Pe, AN and DN to achieve this but don't worry, you have plenty of fuel. You don't need to be exact, as long as the Pe is above 70km (otherwise each time the satellite orbits it will re-enter the atmosphere, be slowed by drag and the orbit will be lowered even more until, sooner or later, the satellite falls to the ground). The inclination needs to be at least 80 degrees to ensure that the satellite 'sees' the poles. How much time you want to spend perfecting the orbit within those bounds is up to you. You are recommended to disable the engine (action group 6) once you've finished making adjustments, just so you don't wreck the whole orbit by accidentally pressing 'shift' at the wrong moment; just remember to re-activate it later, should you come back to make further changes.

Before leaving the satellite make sure it is oriented (WASDQE) so that the solar-panel catches the sunlight properly. If it is blocked by the body of the satellite or is edge-on to the sun it will be useless, your satellite will run out of power and cease functioning. If that happens your only option is to 'terminate' the satellite flight in the tracking centre and try again with another launch. Engage SAS (T) so that the satellite stays in this orientation.

Once all orbital and orientation adjustments are complete activate the SCANSat sensor (action group 7), press esc(ape) or mouse-over the altimeter and return to the Space Centre.

Congratulations – you have carried-out your first useful mission and mapping is underway.



SCANSat Low 7.5km Over Mun

v) Notes

Payload and launch-vehicle should be designed in that order. Decouplers are used to separate the payload and each launch-vehicle stage. For launch vehicles the TWR (Thrust to Weight Ratio) and deltaV (potential velocity-vector change) are vital but not shown by KSP itself. Design for a launch TWR of 1.4 – 1.8 and deltaV of at least 4,500m/s. You are strongly advised to use KER/MJ/VOID to see these figures.

Mapping satellites need to be placed in a (nearly) polar orbit so that they cover different strips of ground as they orbit and the world turns beneath them. With a 'speed' of 0m/s on the surface of Kerbin you're actually already spinning around with the world, that's why a gravity turn directly North ends-up with an orbit slightly East of North. This same initial velocity is what makes a normal Easterly gravity-turn and equatorial orbit slightly more efficient.

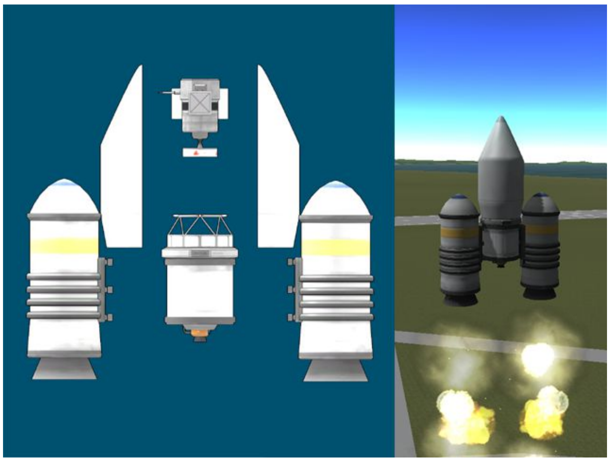
Fairings are purely cosmetic in stock KSP and if you do use them your rockets will be heavier and therefore perform worse (but within the design tolerance). They are jettisoned as soon as you leave the atmosphere because any streamlining they provide with mods is no longer necessary. In particular they should be jettisoned before the circularisation burn so they do not become debris – flying into a panel at over 4,000mph could destroy a later launch!

Once fairings are jettisoned you are free to deploy the solar panels but if you do this in atmosphere they will be torn-off and destroyed.

**** ALWAYS deploy solar panels as soon as you leave atmosphere (after jettisoning any fairings, of course) so they start work as soon as possible. A vehicle without electricity is a dead vehicle! ****

Anything you can't jettison before the circularisation burn – such as the last stage of a launch vehicle – will, by definition, enter orbit. Assuming you don't want to litter space that means it will need sufficient residual propulsion, probe core and electricity to de-orbit itself by burning retrograde after separating from the payload. The probe-core should have enough electrical charge for this as long as you de-orbit soon after separation, otherwise the launch-vehicle will need its own batteries/solar panels as well (which is a good design aim anyway).

SECTION 4: SIDESTEP



Sidestep + SCANSat Mid Launch

i) Data Sheet

Identity	Sidestep – Launch Vehicle
Purpose	Placing a SCANSat satellite in a 250km Kerbin polar orbit
Statistics	9.181t VAB/1.662 dry, 17 parts, cost 8,725
Design	2 radial-staged with dual-SRB first stage
Construction	Upper stage as Two-step. Symmetry-2 TT-38K radial decouplers and RT-10 solid fuel boosters (30% thrust). Aerodynamic nosecones on boosters.
Action Groups	As Two-step.
Performance	(Kerbin) TWR 1.67, 7,249m/s

ii) Construction

The upper stage is identical to Two-step (using a SCANSat Mid satellite as payload, rather than Low). Using radial decouplers instead of a stack decoupler allows us to build out rather than up, which can be useful. It should go without saying that you should make your rockets symmetrical – if you only put a booster on one side of the upper stage (generally known as the 'core' stack when there are radial ones around it) you rocket will almost certainly turn somersaults, but not for long! Whether you prefer radial boosters to just placing them serially, with a bi-, tri- or quad-coupler as on Two-step is up to you. Mostly it doesn't make a lot of difference but long rockets versus wide rockets is a, sometimes contentious, debate on the forums.

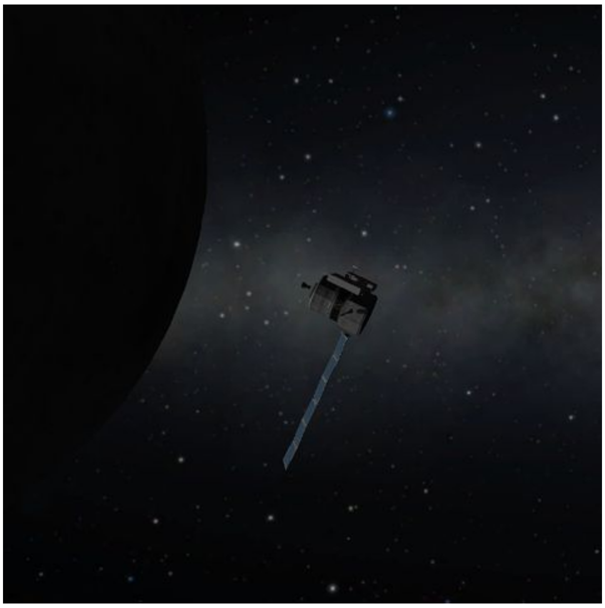
'Moar boosters' is often quoted, usually tongue-in-cheek, on the forums as well. The answer to most design problems is *not* solid fuel boosters (more commonly known as SRBs or Solid Rocket Boosters). They are used in Sidestep to illustrate the differences between them and 'normal' liquid-fuel engines but, looking ahead, are not used in any other designs throughout this tutorial. Again, this is rather a matter of preference; SRBs give a lot of thrust for a relatively short duration and can be very cost-effective but are less controllable than liquid-fuel engines. They are, however, heavy so should only ever be used in a first stage.

Enable symmetry-2 (bottom-left of the VAB screen) and add the radial decouplers and SRBs to the upper-stage/core stack. You'll get a total deltaV of 5,819m/s (great) but a launch TWR of 5.55! (these figures are with satellite and nosecones but not fairings). Never mind exceeding terminal velocity – really high TWRs like this can sometimes tear a vehicle apart. You can't control SRBs with the throttle but you can set their thrust while you are still in the VAB/SPH so right-click on the SRB and reduce the thrust limiter to 30%. This gives a launch TWR of 1.67 without affecting the deltaV – the SRB will burn more slowly for a longer time. 'Tweaking' parts like this can make a lot of difference to your vehicles' performance and is an important thing to remember.

iii) Staging And Action Groups

Identical to Two-step except that the stack decoupler is replaced by the two radial-decouplers jettisoning the first-stage SRBs.

iv) Flight



SCANSat Mid 250km Over Mun

MISSION 9: 250km Polar Orbit

Launch as normal, with a gravity turn to the North. Continue to climb until your apoapsis reaches 250km. Jettison the SRBs when they are depleted and the fairings when you leave the atmosphere (above 69km). Remember to deploy solar panels. Circularise your orbit at apoapsis and note the remaining deltaV, then press escape and revert the flight to launch – there is a different way to get here.

MISSION 10: Hohmann Transfer

Launch again but this time establish apoapsis and circularise your orbit at 75km. Once stabilised there burn prograde at the next periapsis to increase your apoapsis to the required 250km. Circularise in the new orbit at apoapsis as normal and note the remaining deltaV. Establishing a low orbit and then using such a 'Hohmann transfer' to increase it to the desired altitude is more complex, but more fuel-efficient, than going directly to the higher orbit. Mostly this is because you aren't trying to get all that extra height/speed while still in the atmosphere and affected by drag. It is quite possible that you will not notice much difference in the deltaV requirements for these two approaches with a 250km orbit – it becomes more significant as you go further.

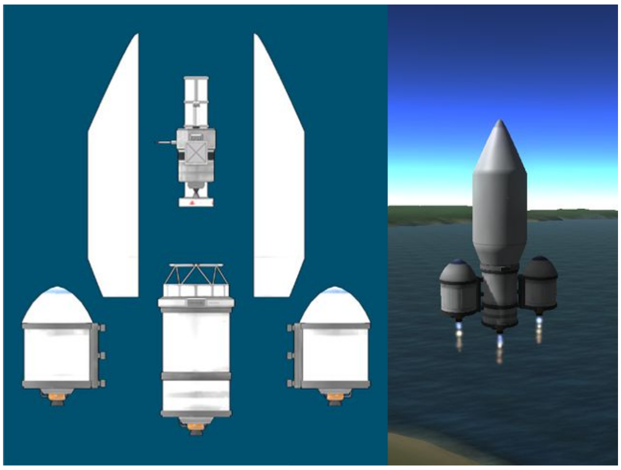
Once you've established your target orbit, decouple the payload and de-orbit the launch vehicle, then adjust the orbit and orientation of the satellite and activate its sensor. That's 2 of 3 in place.

v) Notes

Rocket 1A in the previous chapter is a Single Stage To Orbit (SSTO) design, getting there all in one piece. Serial (also known as Stack) staging, used by two-step, is the classic way to jettison the extra mass of tanks and engines once they have been used. The major difficulty of building serial-staged rockets in KSP is that some engines, or combinations of engines, may make it impossible to fit anything underneath them. Radial staging such as in Sidestep allows you to build wide rather than tall rockets.

SRBs give high thrust but are heavy so only use them in first, launch, stages. Once ignited they can't be turned off or controlled with the throttle but they can be tweaked in the VAB/SPH to balance the thrust against the burn-time. In career mode they can be very cost-effective.

SECTION 5: QUICKSTEP



Quickstep + SCANSat High Launch

i) Data Sheet

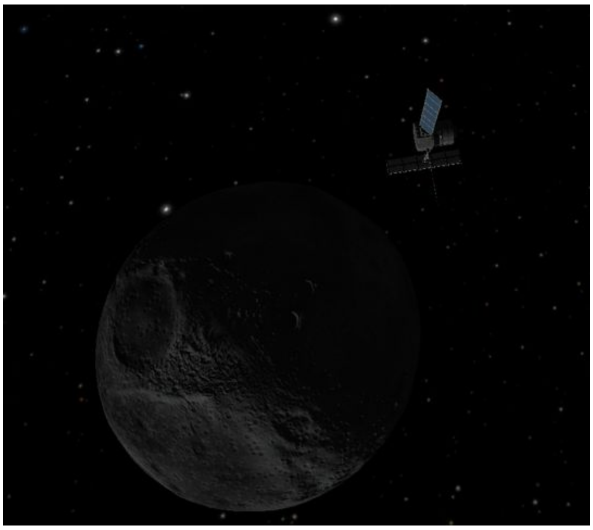
Identity	Quickstep – Launch Vehicle
Purpose	Placing a SCANSat satellite in a 750km Kerbin polar orbit
Statistics	5.261t VAB/1.197 dry, 19 parts, cost 9,950
Design	2 parallel-staged with dual-liquid-fuel first stage
Construction	Decoupler, fairings and RGU as Two-step. FL-T400 fuel tank and 48-7S engine. 2xradial decouplers, FL-T200 fuel tanks, 48-7S engines and nosecones.
Action Groups	abort:shutdown engines, 3:rockets, 4:fairings
Performance	(Kerbin) TWR 1.74, 6,843m/s

ii) Construction

Building this should be easy by now. The payload, fairings and RGU are the same as before, the launch-vehicle core stack is similar but uses the bigger FL-T400 fuel tank. The boosters/first stage use FL-T200 fuel tanks and 48-7Ss instead of SRBs.

The main efficiency problem with serial and radial staging is that the lower stage(s) have to carry upper-stage engines that aren't doing anything. There's not much you can do about that with serial staging, as the upper engines are blocked by the lower stages. Once you move to radial staging, however, the core-stack engines are clear – make them work for their pay! The only difference between radial and parallel staging is that *all* the engines are fired right from the start. Since the core-stack engine has to keep burning longer that means it needs more fuel than the outer boosters. When the boosters are depleted and jettisoned the core continues with its partially empty tank. In later chapters we'll look at ways to eliminate the excess 'partially empty' mass as well.

iii) Staging And Action Groups



SCANSat High 750km Over Mun

Identical to Sidestep but all 3 48-7S engines should be in the lowest stage.

iv) Flight

MISSION 11/12: 750km Polar Orbit

Repeat missions 9 and 10 using the Quickstep launch vehicle and SCANSat High payload and with a target orbit of 750km. Three times as high as the Sidestep orbit (and 10 times that of Two-step), you should see a significant difference between the direct and Hohmann transfer approaches. This is probably the first time you've been so far from the surface too – it really starts to look like space, doesn't it! Compare the picture above of SCANSat High in orbit 750km around Mun with the similar ones in the previous sections of SCANSat Mid (250km) and SCANSat Low (7.5km). You'll be taking them there in the next chapter.

v) Notes

While SSTO and Serial staging are useful there isn't generally a reason to use radial staging in preference to parallel, one rule of efficiency is not to carry engines that aren't pushing. This does not apply to engines and fuel on the payload, of course, as they have to be preserved for the mission use and shouldn't be touched during launch (all rules are made to be broken though and this depends on how you design your ships).

SECTION 6: PROJECT ADDENDUM (Party)

Identity	Project Footsteps Addendum 1 – Project Party
Background	Well done, you've mastered polar orbits, orbital adjustments and Hohmann transfers. You have a set of SCANSat satellites mapping the planet
Objectives	Congratulate yourself
Payloads	N/A
Vehicles	SCANSat Low/Mid/High
Execution	Check-out each of your satellites and get used to the small and big SCANSat maps. Watch them as they start to be uncovered. NB: Especially watch out for any 'anomalies' marked by the Mid satellite. Generally enjoy the view.

Anomalies found by your satellites make good destinations to visit once we start using manned flights in the next chapter. You also want to look out for areas flat enough for landing planes. We won't be using these launch vehicles again but the lessons you've learnt from building and flying them will make the next vehicles much easier.

To infinity, and next door!

CHAPTER 4: PROJECT PERSISTENCE

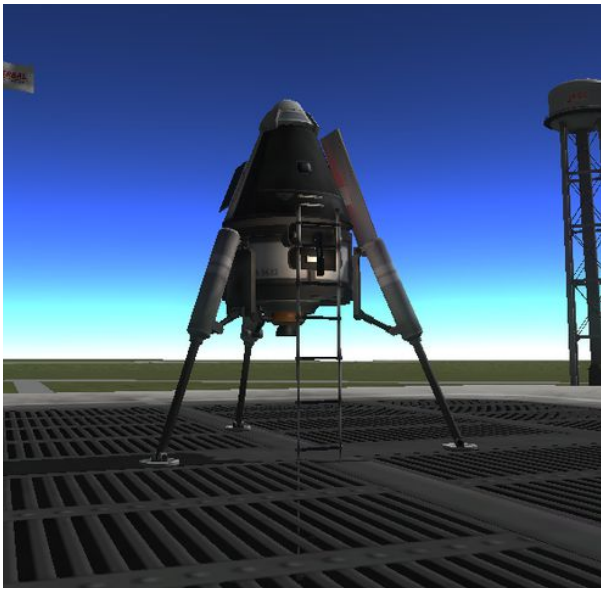
Manned Orbital Flight, Lunar Satellites

SECTION 1: PROJECT BRIEFING

Identity	Project Persistence – Developing Capability
Background	We would like to follow-up the success of the SCANSat satellites with crewed flights into space. In addition we can expand our mapping to Mun, Minmus and beyond.
Objectives	1) Launch a crewed vehicle into orbit. 2) Place SCANSat satellites (one each of Low, Mid and High) into polar orbits around Mun and Minmus, possibly other planets and moons.
Payloads	Orbiter, SCANSat SatStack, Cartographer Light.
Vehicles	LV-2-O, LV-6-O.
Execution	For crewed flight all that is required is a command-pod for a Kerbal to sit in and a launch vehicle capable of placing it in orbit. The satellites require a) combining a set of 3 into a single package, b) building a vehicle that can take this to Mun/Minmus and place them into orbit, c) another launch vehicle to lift the whole lot.

The two objectives of this mission are quite separate and, in the real world, would probably be run as two separate but parallel projects. They do introduce complementary new manoeuvres though – getting to the moons and getting back with a crew. Those are both pretty important before the next chapter – which is mainly about moon-landings.

SECTION 2: ORBITER



Orbiter Payload

i) Data Sheet

Identity	Orbiter – payload
Purpose	Crewed orbital flights
Statistics	1.713t VAB/1.212 dry, 9 parts, cost 2,820
Design	The Mk1 command pod is ideal for a single Kerbal. It'll need a parachute for safe landing and the legs' suspension act as shock-absorbers. Having both is not necessary but redundancy in safety is a good idea. A single solar panel is sufficient plus, if you're using SCANSat, the BTDT sensor. A ladder is always useful. The illustrated fuel-tank and engine are more than enough for coming back from orbit but may also be used for orbital adjustments.
Construction	Command pod Mk1, Mk16 parachute, OX-STAT solar panel, SCAN Been There Done That (BTDT) sensor, Telus-LV ladder, FL-T100 fuel tank, 48-7S engine, 3xLT-1 landing struts (legs).
Action Groups	gear:legs+ladder, abort:shutdown engine, deploy parachute, 6:engine, 7:instrument
Performance	(Vacuum) TWR 1.79, 1,187m/s

ii) Construction

An external command seat is the lightest 'accommodation' for a Kerbal but you can't crew it before launch, which causes all sorts of problems. Let's face it, we really do want the Kerbal sat inside during launch and re-entry anyway. The Mk1 lander can is still lighter than the command pod but isn't intended for atmospheric re-entry so isn't realistic to use either. You may well decide to use it anyway in your more complex missions but this design, based on a Mk1 command pod, is still light enough to be easy to launch and 'looks right'. Safety redundancy is also a feature of this design; the parachute alone should be enough for landing safely, the legs make the vehicle more robust and the engine can use any residual fuel to make touchdown even more gentle. Three landing-legs are used because 3-legged stools don't wobble! More legs are likely to just add unwanted mass without making the landing more stable so aren't worth it.

Develop the habit of always putting solar panels and ladders on things. In practice you won't *need* this ladder but I've lost more than one mission on other bodies because the Kerbal couldn't get back in to come home! Below, you will also see that a ladder is useful just to hang on to. There is no additional battery on this design; the only charge it can store is in the command pod (50). Keep this in mind and make sure the solar-panel is facing the sun after every manoeuvre. In as much as the Orbiter has any ongoing use it is in investigating anomalies on Kerbin (below). For this you will need the SCANSat BTDT sensor.

That just leaves the propulsion. Some is necessary to push the vehicle out of orbit when you want to land and if that was the only requirement the tiniest tank and engine – as used on the satellites – would be sufficient. For looks and utility this design uses the smallest 1.5m tank and the usual 48-7S engine instead. This combination allows for considerable flexibility in making orbital adjustments, as will be discussed in the next section.

Tweaking – I (right clicked on and) removed the monopropellant from the command pod as this design is never intended to dock and doesn't have thrusters. This saves a little mass and mass is critical to deltaV and TWR; another useful habit.

iii) Staging And Action Groups

The parachute should not be needed until landing so that is set as the upper/last stage. Gear toggles the landing-legs and ladder. Abort deploys the parachute as well as shutting-down the engine, just in case. Custom06 and 07 are the same as for the satellites but as the solar-panel is fixed it doesn't need to be deployed.

iv) Flight

The main addition to Orbiter flights from satellite ones is the requirement to bring the Kerbal home alive. You've de-orbited launch-vehicle stages before but this time you'll want to land safely. You may land anywhere – land or sea – aiming at a vertical speed under 10m/s and as near to stopped horizontally as you can manage. Any sideways speed you have at landing will tend to make the capsule tip over, perhaps catastrophically. In any case you should be prepared for it to fall over and roll if you land on a slope, which is pretty likely. Apart from learning to control where you land better there isn't much you can do about that. (Lower, wider, landers are more stable and discussed later).

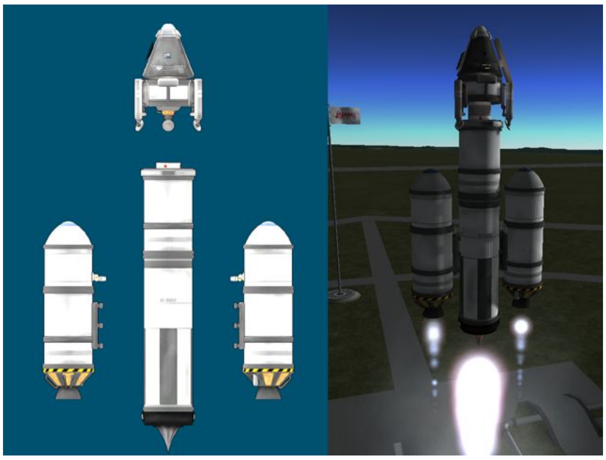
Flights and missions are discussed more in the next section, which details a launch-vehicle for the Orbiter payload.

v) Notes

Make note of the hatch on the command pod – this marks the 'top' of the vehicle and allows you to check its orientation in flight. Make sure the hatch isn't obstructed by, for instance, the ladder. If you place anything blocking the hatch your Kerbal will launch inside it alright but then won't be able to get out! While this may be inconvenient for an orbital flight – you can still land and recover the whole vehicle – it becomes very annoying if you've spent years on a flight to Eeloo only to find you can't plant the treasured flag or retrieve the vital soil sample.

When designing and building vehicles it is useful to do 'ground tests' by clicking launch and checking legs, ladder, action groups, etc. even though you have no intention of actually taking-off. Right-click the legs in the VAB if you would like to start with them extended. Ideally, make sure your Kerbal can exit the capsule, climb down the ladder, let go of it and walk around then return to the ladder, climb up and re-board the capsule.

SECTION 3: LV-2-O



LV-2-O + Orbiter Launch

i) Data Sheet

Identity	LV-2-O – launch vehicle
Purpose	Kerbin launch. 2 tonnes.
Statistics	(ex payload) 16.225t VAB/4.225 dry, 17 parts, cost 14,880
Design	2 onion-staged. This is an extension with fuel-lines of the core + 2-boosters design used for the satellites.
Construction	TR-2V decoupler, core:RC-001S RGU, FL-T400 and FL-T800 fuel tanks, aerospike engine. Boosters: 2 x radial decouplers, FL-T200 and FL-T400 fuel tanks, LV-909 engines, nosecones and fuel-lines.
Action Groups	abort: shutdown engine, 3:engines
Performance	(Kerbin) TWR 1.73, 6,626m/s

ii) Construction

Orbiter EVA

There is quite a jump in the payload mass for this vehicle – Orbiter at 1.713t is more than 7 times the satellites used before. That means that although the basic core + 2-boosters design is similar it needs more powerful engines and considerably more fuel. Complete with the Orbiter payload LV-2-O masses just under 18t which represents a payload ratio of 9.55% - barely adequate. An adequate launch-vehicle should provide a payload-ratio of at least 10% (9 tonnes or less of launch-vehicle per tonne of payload) but this design does a lot better than the 4.49% of Quickstep in the previous chapter! It can be difficult to make an efficient launcher for small payloads, and 2 tonnes is very small, because there are few options available for fuel tanks and engines. Nevertheless 15% payload ratio is a reasonable target and 20% (9 tonnes of launch-vehicle for every 2 tonnes of payload) is sometimes obtainable. The vehicles in this tutorial are intended to illustrate design methods rather than efficiency but are getting better.

The fuel-lines on this design must be attached first on the booster tanks and then on the core. There are arrows on the lines themselves that indicate this is the way fuel will flow. Using this arrangement the core engine will first take fuel from the booster tanks, as will the booster engines themselves. When these tanks are exhausted they can be jettisoned and the core uses its own, still full, tanks for the rest of the flight. This is known as 'onion' staging because the outer layers are used/peeled-off completely before the inner one(s) are touched. In section 9 is an example of symmetry-3 onion staging with two outer layers. Fuel-lines are the difference between parallel and onion staging.

Using-up and jettisoning as many tanks/engines as possible using fuel-lines is the key to improved staging efficiency. You should note, however, that no rockets have used fuel-lines like this in real life, even though the concept of drop-tanks and side-boosters is common. For this reason some people on the forums consider KSP fuel-lines 'wrong'. Personally, I don't think KSP's other-universe rockets should be restricted to 60 year-old Earth technology but you might want to put such a restriction on your own designs.

NB: There are no fairings around the payload – I think Orbiter is aerodynamic enough.

iii) Staging And Action Groups

Orbiter De-orbit

The lowest/first stage fires all the launch-vehicle engines, the second jettisons the boosters when depleted. Once in orbit the third stage is to separate the payload. Assuming you are using the Orbiter payload its engine is also activated in this stage, with the parachute being left for the fourth/last/upper stage.

Apart from Custom03 to toggle the launch-vehicle engines (if you wish), just add the engines to the abort action group, along with the payload separator. This last provides an 'escape system' – you can abort, separating the capsule, and deploy its parachute, should you need to.

iv) Flight

NB: All launches should be to a standard, equatorial, orbit (inclination 0-degrees) from now on. Kerbin is rotating to the East so 'stationary' on the ground you already have some 'orbital' velocity in that direction and it is more efficient to take advantage of this by launching in that direction. In contrast a launch to the West, while entirely possible, has to overcome this initial velocity while reaching orbital speed in the opposite direction. Other orbits (such as the polar ones of the previous chapter) require correspondingly higher deltaV depending on their inclination from 0 degrees.

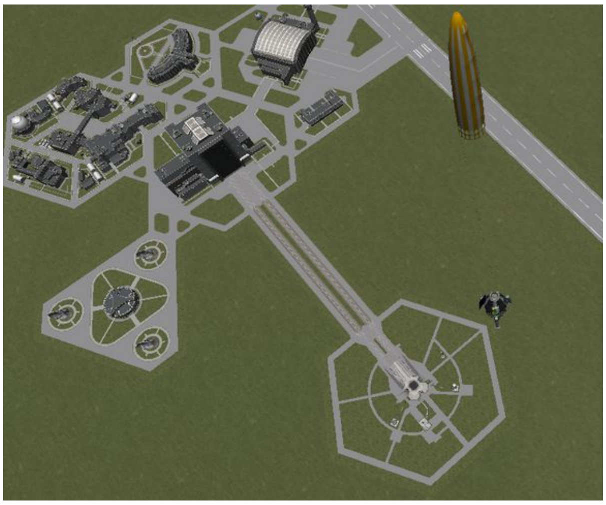
MISSION 13: First Kerbal In Space

Orbiter Re-entry

Launch! You should not have any problems with this vehicle, having used those from the previous chapter to put the satellites into polar orbits. Just remember to do your gravity turn to the East (yaw right, D) this time – as you should have been doing for the prologue Rocket 1A/B. Stage to jettison the boosters when they run out of fuel. Circularise your orbit at 75km apoapsis. Separate and de-orbit the last of the launch-vehicle as normal. Make sure the sole solar-panel is facing the sun!

Congratulations – you have a Kerbal in space. You may use the Orbiter engine to make 'orbital corrections' if you wish but make sure you leave enough fuel (preferably 200m/s deltaV or more) to de-orbit. The more you leave, the more you'll be able to control your landing.

While you're up here:
a) Make and remove manoeuvre nodes to see how much you can adjust your orbit with the fuel available. Changing orbital height (prograde/retrograde burns) is fairly cheap in terms of deltaV – you have enough to fly-by Mun if you wish, just make sure you get a 'free return' trajectory that brings you back to Kerbin or you'll be stuck in space. Burning (anti)normal will adjust your orbit's inclination, as you've probably tested with your satellites. This is relatively expensive but is cheaper the slower you're moving because there's less orbital speed to counter/change. You'll be moving slower at apoapsis and slower still with a higher apoapsis. Ideally you change planes by increasing apoapsis, changing inclination at the new apoapsis and finally reducing the apoapsis again. Check it out, there's no need to do the burns unless you want to, just practice with the manoeuvre nodes.



Orbiter Parachute Semi-deployed

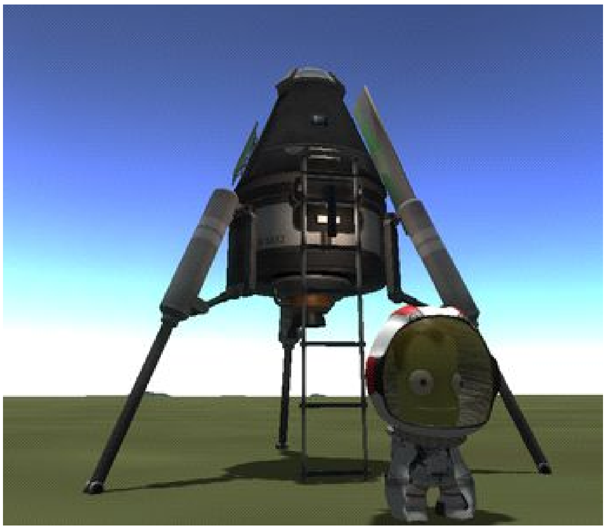
b) Spacewalk! EVA = Extra-Vehicular-Activity = getting out. Click on the EVA button that appears when you mouse-over the portrait of your Kerbal or click on the pod hatch. You may like to extend the ladder before doing this as it gives the Kerbal more to hold on to. Be warned: KSP spacewalks are not tethered. Spacesuits include an RCS pack (R to activate) but if you exhaust its fuel without grabbing-hold of the vehicle again there's no way to get your Kerbal back – apart from launching a rescue mission, which you're probably not yet ready for. If you have extended the ladder you'll be able to move the Kerbal down (S) and back up (W) it once they are outside the pod. Press F to re-board the pod when near the hatch (a prompt will be displayed). When you feel brave enough press space to let go of the pod/ladder, then press R to activate the suit's RCS. You may want to use the helmet lights (L) as well. There are no instruments displayed while you're controlling a Kerbal on EVA so you'll have to do everything by eye. Use fine controls (caps-lock) and very light taps of the keys to keep the speed slow and don't go too far from the pod while you're learning. In EVA mode W moves the Kerbal forward and S backwards. A/D and Q/E move and rotate them left/right. To move up or down use shift/ctrl, usually the throttle keys. While floating in space if you are ever close enough to grab hold of the pod (or ladder, if you extended it) you will be prompted to press F to do so. Re-boarding the pod (not just grabbing it) will refuel your RCS pack infinitely and without affecting the pod's own supply. You can also right-click on a few parts while the Kerbal is near enough to them, which lets you; i) extend the ladder (in case you forgot!), ii) fix broken legs and wheels, iii) repack used parachutes.

Orbiter Parachute & Legs Deployed

Once you're ready to come home:
(Re-board the pod first of course!). Turn the vehicle to face retrograde and burn to de-orbit, just as for the final launch-vehicle stages. Unlike just letting them be destroyed on re-entry though watch where your orbit-line touches the surface and use the engine to make adjustments. Once you re-enter the atmosphere drag will cause you to fall short of this point. If this is the first time you've watched something during re-entry enjoy the plasma-show between around 20km – 10km then deploy the parachute around 1km up. You can deploy it higher, for more drag, but don't need to. Have fun, try to remember to extend the landing-legs before you touch down. Use the engine and any residual fuel to see how gently and accurately you can land.

You may well want to repeat this mission several times to practice orbital adjustments, EVA and picking your landing site. Get used to how much the atmosphere slows down your descent and makes you land short of the initial prediction (where your orbit line hits the ground after the de-orbit burn). Landing at KSC itself is good for bragging rights and the closer you land to it the more money you will be paid in career mode when you 'recover' the vehicle.

v) Notes



Orbiter Landed

Fuel-lines can make staging more efficient, keeping the inner tanks full and using-up the outer tanks as quickly as possible, to get everything you can from them without having to carry them around for long. Changing orbital altitude is relatively cheap, changing planes (inclination) isn't but gets cheaper the higher your orbit. You have infinite EVA fuel if you keep re-boarding the command pod but if it runs out in space your Kerbal is stuck – be careful! Use very short taps and keep your (relative) speed down. After re-entry, drag will make you fall short of your initially-predicted landing site. If you haven't GOT a predicted landing-site because your periapsis is above-ground it will still be reduced by drag as long as you are flying through the atmosphere. This 'aerobraking' is an efficient way of reducing your orbit without using (much) fuel, but it may take several orbits before the periapsis finally reaches the ground. Not to be confused with 'lithobreaking', a common forum phrase. Atmosphere is where the air is, the 'lithosphere' of a body is where the rocks are (i.e.; stopping by hitting the ground – not generally recommended!). If you don't have enough fuel to lower your periapsis into the atmosphere at all... you're stuck until you can launch a rescue mission. One, very Kerbal, solution is to 'get out and push' - you have infinite EVA fuel so get the Kerbal to push the pod retrograde using the suit RCS, slowing the vehicle and lowering its periapsis. Re-board the pod to refuel the suit, repeat as required until the periapsis is in the atmosphere and aerobraking will do the rest for you.

SECTION 4: PROJECT ADDENDUM (Back To The Hanger)

Identity	Persistence Addendum 1 – Orbiter Mk2
Background	The engineers and ground-crew in the Spaceplane Hanger (SPH) are a bit annoyed that they haven't been asked to contribute to the space program at all. In consequence they have designed and built an orbital spaceplane they claim out-performs the Orbiter vehicle while also being completely reusable.
Objectives	Test and evaluate the Orbiter Mk2 design.
Payloads	N/A
Vehicles	Orbiter Mk2.
Execution	Launch, fly, orbit and land using a plane instead of a rocket. Optionally dock two spaceplanes in orbit.

The way to fly spaceplanes is very different to flying rockets. The big difference is that you take oxygen from the air instead of carrying heavy oxidiser. This means building horizontal speed using jet engines, ideally reaching orbital speed (~2,200m/s) with them and only using rockets to circularise your orbit in space. Flying a spaceplane requires more of your time and effort, which some people find rewarding, some don't. Landing is, again, harder and longer but gives more control – something that flight-simulator fans enjoy more than most people. Apart from Kerbin, spaceplanes are only really useful on Laythe; that being the only other place that has an oxygen atmosphere for jets.

Rendezvous and docking are very important for most extended missions but need not be practiced yet. They are, however, a feature of every chapter from now on.

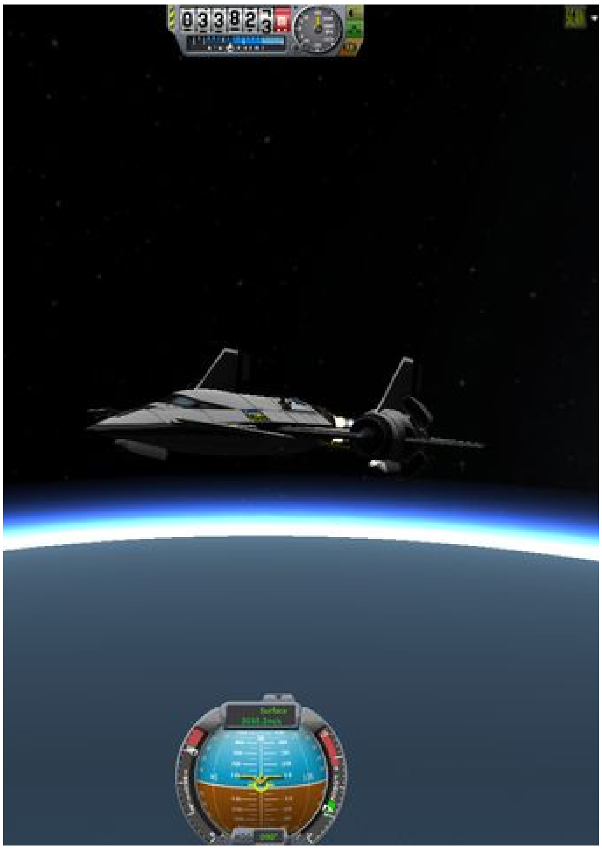
SECTION 5: ORBITER Mk2

Orbiter Mk2 in SPH

i) Data Sheet

Identity	Orbiter Mk2 – spaceplane
Purpose	2-man orbital flights
Statistics	6.906t SPH/4.63 dry, 39 parts, cost 33,030
Design	A good-looking plane that is easy to fly to orbit and back.
Construction	Mk2 cockpit, clamp-o-tron, rocket fuel fuselage short, inline reaction wheel, rapier engine. 2x standard canards (pitch), delta wings, engine nacelles, tail-fins, elevon 4s for yaw control. 2x eleveon 1s on inner trailing-edge of wing for pitch and 2 more on outer for roll. Shock cone, 2x XM-G50 radial air intakes and fuel-lines to core tank on each nacelle. 4X RCS thrusters around CoM, OX-STAT solar panels behind them and 3x small gear bay under cockpit and nacelles. Telus-LV ladder.
Action Groups	Gear, light, brakes:standard, abort:shutdown engines, 1:toggle engine, 2:intakes, 3:switch mode, 4:docking port, 5:ladder, 6:cockpit lights, 7:instrs
Performance	(Kerbin, air-breathing) Takeoff/Landing 60m/s, Ceiling ~36km, max speed ~2,100m/s

ii) Construction



Orbiter Mk2 High & Fast

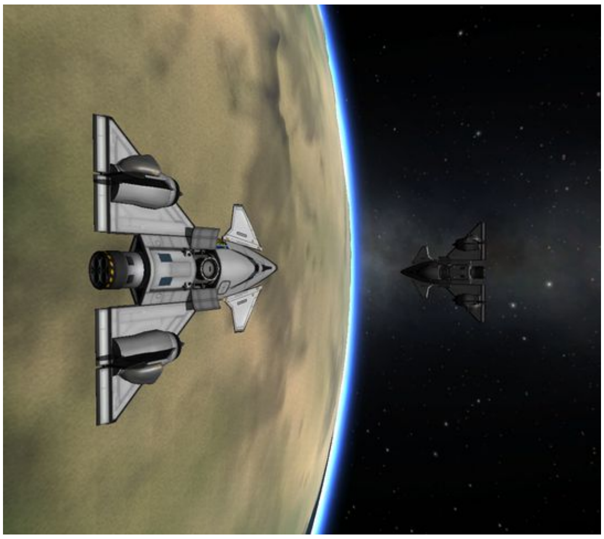
The 'Mk2' series parts are *the* parts most people use for spaceplanes in KSP, so here we go, starting with a cockpit. To dock it'll need the clamp-o-tron and the rocket fuel fuselage includes oxidiser for in-space work. During ascent and landing the engine takes oxygen from the atmosphere instead and the nacelles just contain liquid fuel. They and the intakes on them provide this oxygen that the engine uses. Tweak the control-surfaces (canards and elevons) as indicated in the table above. There is one crafty trick to building this spaceplane – in order to put the nacelles in the middle of the wings, as shown, you will first need to put them on the top or bottom of them. Then use the 'offset' button at the top-left of the SPH screen and 'pull' the nacelles into the correct position.

Jet engines are very fuel-efficient compared to rockets in KSP but can only work in an oxygen atmosphere. In space spaceplanes need a rocket-engine for thrust, just like any other vehicle. Generally they have turbojet engines for in-atmosphere work and normal rockets for orbital manoeuvres but this design uses a rapier engine instead. The rapier engine can work like a jet in atmosphere and a rocket the rest of the time, so it is simpler. The drawback is that it doesn't offer the same thrust or efficiency as the specialised engines, so it is a matter of taste whether you want to use it in your own designs.

In the prologue the balance of aircraft was skipped and for rockets it rarely matters as long as they are symmetrical. Aircraft rely much more on their aerodynamics though and the relative positions of the Centre Of Mass (CoM) and Centre of Lift (CoL) is vital – as is the placement of the rear landing-gear in relation to the CoM. The Centre of Mass is the 'balance point' of a vehicle – if a model were suspended on a string from this point it would stay level. All forces acting on the plane are, in effect, pushing or rotating this point. The engine will turn the plane as it burns, for instance, unless its Centre of Thrust (CoT) is directly in line with the CoM. (Technically, the *axis* of thrust, opposite to the arrow shown in the SPH, has to run through the CoM). Similarly, if the CoL is in front of the CoM the plane will tend to flip nose-up and, if it is behind, it will tend to flip nose-down. A plane that wants to nose-up sounds good but, in practice, will tend to 'back flip' and become uncontrollable. In practice you should adjust the wings and control-surfaces backwards and forwards so that the CoL is just behind the CoM. Pitch-up controls and trim (S, alt-S) should be able to counter the tendency you then build-in for the plane to nose-down. If you move the CoL too far back you'll have a plane that won't nose-up and climb at all, but at least then you don't get off the runway! The canards help with takeoff by adding extra pitch-authority (strength of the controls) ahead of the CoM and, especially, lift the nose during launch. Another thing that may stop your aircraft taking-off at all is the position of the rear landing-gear. If these are in front of the CoM (or very close to it) the plane will tip back onto the engine on the runway, which isn't good. If they are too far back, however, the wing-lift won't be able to rotate the plane's body around them so, again, you'll never climb. Ideally they should be as close behind the CoM as you can put them without the plane tipping-up on the runway. There are some very good spaceplane tutorials on the forums and you will probably need to read several of them before becoming proficient at designing your own.

This is the first vehicle in this campaign tutorial to feature RCS fuel and thrusters. These are low-velocity jets rather like spray-cans that are used to gently 'nudge' a vehicle's attitude and position, normally during docking. Mainly, these are the only easy propulsion tools for moving your vehicle 'sideways' to align with another docking-port. They give much better low-speed fine control but also need to be placed in a balanced arrangement. The most flexible setup is to have 4 thrusters around the nose of a vehicle and 4 around the tail, placed at an equal distance from the CoM so they rotate the vehicle smoothly around it. The arrangement shown is somewhat simpler in that there is only one set of 4 thrusters, arranged around the CoM itself. If you do not balance the thrusters around or on the CoM you will get translation while trying to rotate and vice-versa. Stock KSP doesn't show you the CoT for thrusters but the RCS Balancer mod will, should you install it. RCS uses monopropellant instead of liquid fuel, it is included in all command pods.

iii) Staging And Action Groups



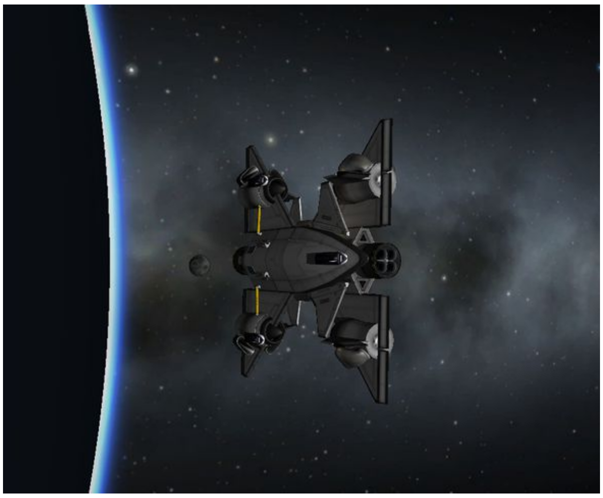
Orbiters Mk2 Rendezvous

The gear, lights and brakes are all standard, apply to the landing-gear and are set by KSP automatically. The engine is toggled with action-group 1 and switched between modes (air-breathing jet or closed-cycle rocket) with 3. Intakes can be closed to reduce drag and re-opened for air with 2. 5 and 7 follow my standard ladder and instruments settings. The docking port must be opened before use and this is assigned to action group 4. You can now see why 1-3 were reserved for launch-vehicles/spaceplanes, although real spaceplane enthusiasts may want better control over the engines and intakes and will dedicate more action-groups to toggling them open and closed as required.

'Staging' isn't really applicable to spaceplanes as they stay in one piece (most of the time). If you do use it I'd recommend jet(s) in the first stage, rocket(s) in the next, when you have them, and 'abort' parachutes, etc. in the last.

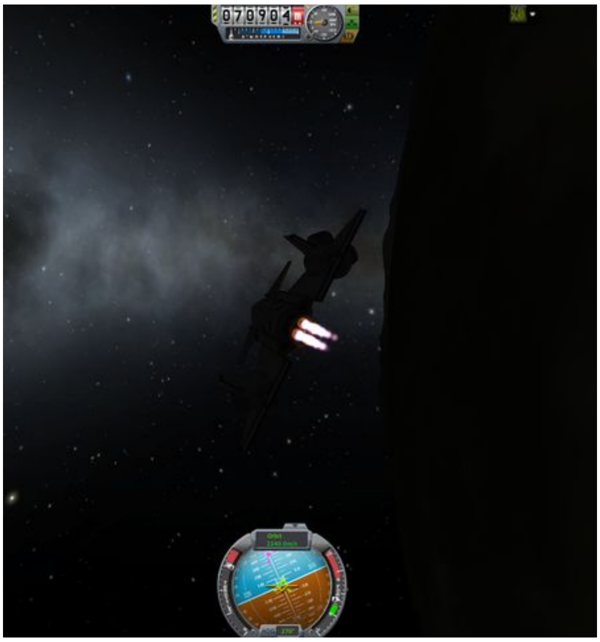
iv) Flight

MISSION 14: Fly Into Space



Orbiters Mk2 Docked

Getting a plane into space is more involved and time-consuming than getting a rocket there but the rapier engine keeps it fairly simply. Ascent is split into three main phases, instead of a single gravity turn: get above high-drag air, get speed in low-drag air, complete ascent using closed-cycle when the air runs out. Launch, on the runway, toggle fine-controls (caps lock), chase-mode camera and the engine. Engage SAS, throttle to full, rotate to a 50-degree climb at 60m/s, retract gear, maintain climb to 20km then pitch-down to 10-degrees for the 'speed run'. Your objective through the middle phase is to build as much **horizontal** speed as possible with the air-breathing (jet) mode and because the air gets thinner (lower drag, higher terminal velocity) as you go up, the higher you go the faster you can go. Because the air gets thinner though, the higher you go the faster you have to go to get enough intake air for air-breathing to work. Climb too slowly and drag will keep your speed down. Climb too fast and the rapier will get insufficient air and switch to closed-cycle (rocket) mode. The initial climb is just to get to the relatively-thin air above 20km, from here it's a balancing-act to regulate your vertical speed so that your horizontal speed continues to increase as fast as possible. With this design you should be able to get to 36km and 2,100m/s before the engine switches to closed-cycle. Then press 2 to close the air-intakes and reduce drag. The final push to orbit in closed-cycle is similar to any launch but let your apoapsis go to 80km or so because you're still relatively low in the atmosphere and will lose more height to drag than with a normal rocket ascent. Circularise at 75km as usual. All this final phase should only take a very small amount of fuel and oxidiser and even with the fuel used in air-breathing mode is much more cost-effective than a pure rocket – plus you haven't had to jettison any expensive components. If you manage to land again you have a completely reusable vehicle.



Orbiter Mk2 De-orbit

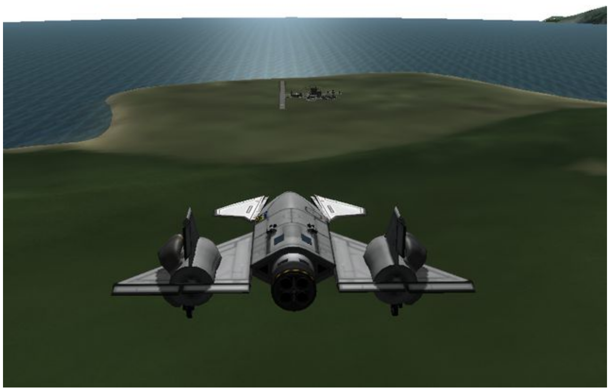
De-orbiting and landing with the Orbiter Mk2 are similar for the Orbiter rocket except that you should select a landing-point 10-20km or so before where you really want to go – you can fly the rest of the way. After your de-orbit burn turn to and hold prograde until you have dropped through the re-entry effects back down to 10km (where there is plenty of air for air-breathing again). The temptation is to try to take control of the vehicle too soon – if you do it'll probably stall or spin then crash; just let it fall! Once back in the thick air below 10km open the air-intakes (2) again and toggle the engine (3) to air-breathing. Throttle-up to 30-50% and slowly bring the nose up (S and alt-S for trim) so that you are flying more-or-less level and back in control around 4km above and from your landing-site, ideally the KSC runway. You may want to dive some more to get on your preferred approach-path and can then reduce throttle to follow the glide-slope to a normal landing. Good luck, remember to lower your landing gear. (Assuming you are aiming for the KSC runway be aware that the mountains to the West of KSC reach around 4km themselves – you don't need to come down that far West anyway, 20km from the runway is more than enough). This is ALL much, much easier if you have a mod (KER, MJ, VOID) that shows you vertical and horizontal speed, heading and distance to target.

MISSION 15: (Optional) Fancy Seeing You Here

Orbiter Mk2 Re-Entry

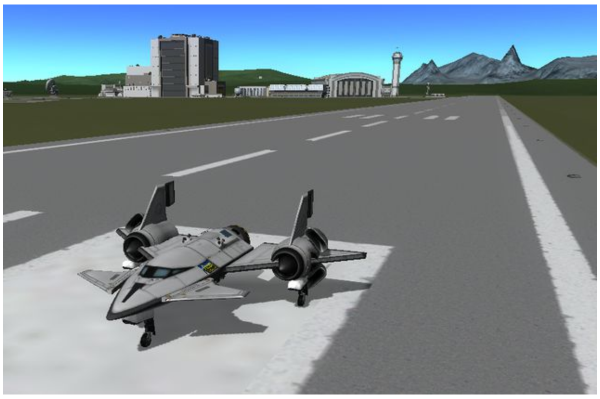
Orbiter Mk2 has a docking-port and RCS fuel/thrusters. This is your first opportunity to launch two of them and try to rendezvous and dock in orbit. For the initial rendezvous note that you want the two vehicles to start in different orbits – 75km and 150km, for instance. This means their orbital periods will be different and the one in the lower orbit will go around faster. Match planes once the orbits are established and then wait for the vehicles to come into alignment. Sooner or later a Hohmann transfer from one orbit to the other – and it doesn't matter whether you dock with the higher or lower vehicle – will bring the two vehicles within a few kilometres, where you can circularise and use minimum-throttle or RCS to bring your relative speed to 0m/s. Docking, once you've got a close enough rendezvous and come to a relative stop, is much easier with a docking-alignment mod. Select the docking port on the other vehicle as your target and 'control from here' on the docking port on your vehicle. Remember to open both ports (action group 4), keep your relative speed down, take it all slowly, make small adjustments and don't panic!

v) Notes



Orbiter Mk2 Line-up

You'll have to practice taking-off and flying high and, particularly, fast before getting to orbit reliably. Then you can practice re-entry, then landing with this design. That last step can be practiced with circuits-and-bumps but recovering from re-entry to normal flight will still be the last part you can attempt. Quicksave (F5) before de-orbit burn. Try flying this to orbit several times, adjusting your pitch and thus horizontal vs. vertical speeds. Try manual instead of automatic mode-switching for the highest horizontal speed in air-breathing mode, to use as little oxidiser as possible. Don't sweat the rendezvous and docking too much – there'll be rather more of it in the next chapter.



Orbiter Mk2 Landed

SECTION 6: PROJECT ADDENDUM (What In The World)

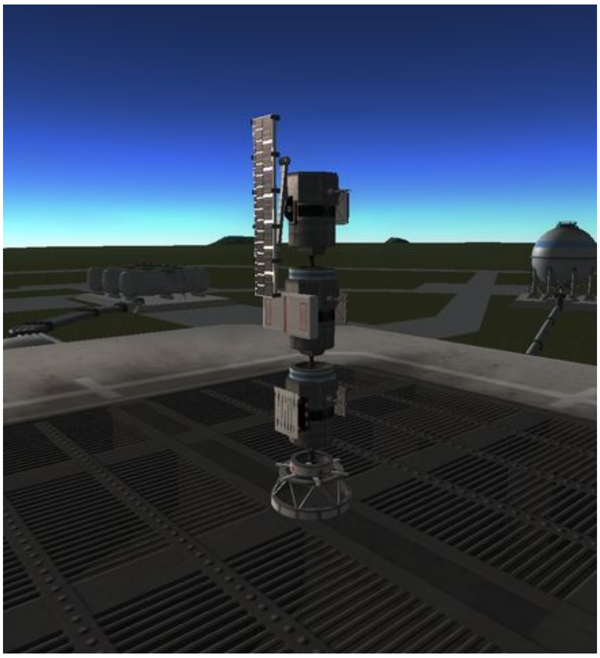
Identity	Persistence Addendum 2 – Anomaly Investigation
Background	Identify anomalies as your SCANSat Mid satellite locates them.
Objectives	Use a SCANSat BTDT sensor to identify the anomalies.
Payloads	Orbiter (if not using aircraft).
Vehicles	Trainer Mk1, Orbiter Mk2 or LV-2-O (with Orbiter).
Execution	The BTDT sensor only works within 2km so you need to fly a vehicle at least that close to find out what the anomaly is. You will probably want to land close enough to have a look around for a screenshot or two.

You have a choice of launching an Orbiter, possibly sub-orbitally, and landing at an anomaly site or flying a Trainer Mk1 or Orbiter Mk2 there. Trainer Mk1 (from the prologue) is easiest to land where you want but slowest and has a limited range. The Orbiter rocket is quickest but you'll have to practice 'precision' landings – within 2km of the target anyway. An Orbiter Mk2 is the most flexible vehicle, being able to fly in atmosphere as well as go full-orbital if you need to but it will take more effort than the rocket.

I recommend that you check-out those near to KSC with Trainer Mk1 for the flight and landing practice. Use Orbiter or Orbiter Mk2 for further ones based on whether you enjoy flying aircraft in atmosphere or not. In any case you can take each of these anomalies in your own time and will probably want to become reasonably proficient with each type of vehicle at your own pace.

Orbital inclination changes require a lot of fuel. You will find that for targets far from the equator it is much more efficient to launch into an inclined orbit that passes over the target rather than trying to change from an equatorial orbit.

SECTION 7: SCANSAT SATSTACK



SatStack Payload

i) Data Sheet

Identity	SCANSat SatStack – payload
Purpose	Single-launch, multiple-delivery
Statistics	0.91t VAB, 25 parts, cost 44,917
Design	Nothing clever here. A set of Low, Mid and High satellites in one payload package. Separators between the 'upper' two keep them clear of obstructions but are left as debris. Normal decoupler on the bottom one stays with the transfer vehicle.
Construction	SCANSat High, TR-2C stack separator, SCANSat Mid, TR-2C separator, SCANSat Low, TR-2V decoupler, fairings base.
Action Groups	N/A - } individual
Performance	N/A - } SCANSat satellites

This is just a set of SCANSat satellites packaged into a single payload. Cartographer Light (in the next section) is going to carry this stack to the moons and easier planets, rather than launching each satellite individually.

ii) Construction

The illustration shows the three satellites attached to the fairings-base (Procedural Fairings) with a TR-2V stack decoupler as before. As you will have seen in previous rocket launches, a decoupler stays attached to one stage, it is the part to which the arrows on it point that is decoupled. Usually that means the decoupler stays attached to a depleted lower-stage and the whole thing returns to the atmosphere and is destroyed. In the case of these satellites, however, both 'stages' have a job to do, they are being separated so they can move to their own orbits and carry out their mission. At the very least we don't want any of them to have to carry the mass of a decoupler with them, but in addition it is often impossible to place a decoupler without fouling an engine or instrument. Separators, such as the TR-2C used here, are different in that they detach from both sides. When you 'stage' the top satellite, for instance, not only does it detach from the separator, leaving its engine clear, but the separator also detaches from the satellite beneath it, leaving the instrument and solar-panel clear. Unfortunately, this does mean the separator is left as debris in space; you'll have to 'terminate' it (with extreme prejudice) in the tracking station.

iii) Staging And Action Groups

The separators/decoupler should be staged from 'upper' (separators) to 'lower' (decoupler) so the rest stay with the transfer vehicle while those above are placed into their correct orbit.

The satellites still use 6-8 for their engines, instruments and solar panels, as before.

iv) Flight

A payload. Flights are discussed in section 9.

v) Notes

The stack as illustrated is designed to separate in the order High, Mid, Low. You may prefer to deploy them in the reverse order. Saving the individual satellites as sub-assemblies in the VAB means you don't have to rebuild them just to join them together in a stack. If you do this, note that you will only be able to attach them using the free node of the original root part. That means you have to join the tops not the bottoms - what is the effect of carrying them to space, and their target moon/planet, backwards? Not much, really – just turn them around once they separate. Remember the rover from the prologue though? If one of the upside-down satellite probe-cores (the Oktos) ends-up as the root part of your complete rocket then the navball will point DOWN when you come to launch. There are many ways around this – the easiest being to 'control from here' on the probe-core for the launch vehicle (unless you build that upside-down too!) – but it can catch you out if you forget.

SECTION 8: CARTOGRAPHER LIGHT

Cartographer Light Transfer Vehicle

i) Data Sheet

Identity	Cartographer Light – transfer vehicle
Purpose	Lunar and interplanetary satellite delivery
Statistics	(inc SatStack) 5.554t VAB/1.362 dry, 27 parts, cost 48,910
Design	A simple vehicle that doesn't need a high TWR as it is only intended to operate in space.
Construction	(SatStack with fairings payload), RC-001S RGU, FL-T800 fuel tank, 48-7S engine.
Action Groups	abort:shutdown engine, 4:fairings, 5:engine
Performance	(Vacuum) TWR 0.55, 4,662m/s

The primary satellite objectives for this project are Kerbin's moons. The first question then is, what does it take to get to the moons, then what does it take to establish orbits around them? What, in fact, is it that we need to know in order to design for such a mission? The answer is very simple – to get to the moons all you need to know is the deltaV to match orbital plane around Kerbin with your target then raise your orbit to match it. Plane-changes and Hohmann transfers to higher orbits are both manoeuvres you should have become familiar with so, for Mun at least, the only other thing you need to know is given by a deltaV map, such as:

http://i.imgur.com/NKZhU57.png

Cartographer Light will be launched into Low Kerbin Orbit (LKO: a standard 75km, equatorial orbit) so add-up the numbers shown from there (bottom of the diagram) to Low Mun Orbit. That is; 680 + 180 + 80 = 940m/s to get to Mun (a fly-by) plus 230 = 1,170m/s to establish orbit around it. In the next chapter we'll talk about landing (the last 580m/s) and coming back but these satellites will do neither; so 1,170m/s is our requirement for Mun. The individual satellites will need to transfer from Low Mun Orbit to their operating altitudes but they have plenty of their own propulsion for that, as you will have seen. Going to Minmus is similar but slightly more complex in that it is not on an equatorial orbit around Kerbin. To get there Cartographer Light will need to perform a plane-change first of 340m/s, less if you launch into a more compatible orbit. The trick here is that you not only need to get the right inclination (6 degrees) but at the right time, or you could end-up 6 degrees in the wrong direction, for a total miss of 12 degrees; check the tutorials on this. Once you are orbiting in the correct plane the Hohmann transfer is as for Mun and will total; 340 (plane-change) + 680 + 180 (as Mun) + 70 + 90 = 1,360m/s (flyby) + 70 = 1,430m/s (orbit). Note that the Orbiter described at the beginning of this chapter has enough deltaV for a fly-by of Mun but not Minmus. It doesn't quite have enough to orbit even Mun (and wouldn't be able to get back if it did).

For such space-only operations there is no need to worry about TWR as we don't have to fight out of the gravity-well, any thrust will adjust our orbit. Having a high TWR means a vehicle can accelerate (apply the deltaV) more quickly and therefore you won't need to burn the engines for so long but, although helpful, it is usually not worth adding engine mass just to achieve it. My patience tends to run out with a TWR below about 0.2 and I try to design for at least 0.4 but you may prefer a lower figure with lighter engines and consequently lower overall mass to launch in the first place.

Our transfer vehicle therefore needs at least 1,430m/s deltaV to deliver the satellite stack. We're meant to be "halfway to anywhere" once we're in orbit though so it's worth asking how much harder would it be to go, well, anywhere? Ike, Duna's moon, is the next easiest (lowest deltaV requirement) place to orbit, followed by Duna itself (without using atmospheric braking). They only need 1,550m/s and 1,700m/s respectively, including plane-change and, given that the plane-change is so much less than for Minmus, are in some ways easier. Interplanetary takes less than half the deltaV required to get to orbit! In fact, for the 4,500m/s it took to get to Kerbin orbit we can transfer to low orbits around all but Eeloo (4,790m/s), Jool, Bop, Moho and Kerbol (the sun) itself. The hardest of the planets, Moho, only requires 6,640m/s, so not wildly more than we're used to building. That, however, is from LKO so we'll soon be launching payloads (the transfer vehicles plus *their* payloads) bigger than the total launch-vehicles we've so-far seen. Low-orbit around Kerbol itself requires 33,680m/s deltaV according to the map and is outside the scope of this tutorial.

In summary:

"How hard is it to transfer to and orbit (from Kerbin LKO, m/s)?" table

Mun	1,170
Minmus	1,430
Ike	1,550
Duna	1,700
Eve	2,880
Gilly	2,950
Dres	3,860
Tylo	3,860
Vall	3,890
Pol	4,040
Laythe	Kerbin orbit 4,500m/s "Halfway to anywhere" -> 4,360
Eeloo	4,790
Jool	5,170
Bop	5,920
Moho	6,640
Kerbol	33,680

ii) Construction

NB: The TT18-A launch stability enhancer (launch clamp) in the illustration is only there to hold the rocket up for the screenshot; you don't need or want one for the real thing.

If we were designing for lunar then we wouldn't need very much at all – just a 90-unit FL-T200 fuel tank and another LV-1 engine, as used on the satellites themselves, gives 1,831m/s deltaV and a just-about acceptable 0.19 TWR. That'll take us to Ike and Duna as well as the moons! As it's so easy though it's worth looking at something just a little more capable. The design as illustrated uses the old favourite 48-7S engine and the largest 1.5m fuel tank – the FL-T800. That's more than needed to orbit Minmus and sufficient for delivering the satellites to every planet and moon up to and including Laythe in the table above. The TWR is still a little higher than it needs to be so we could just add more fuel and go further. I haven't done that in this design because a) shorter burn-times (higher TWR) will make things easier for your first trips away from Kerbin, b) in the next chapter we'll discuss 'Cartographer Heavy' which uses the most efficient space-based engine.

iii) Staging And Action Groups

Action groups 1-3 remain reserved for launch vehicles and 6-8 for payloads. Cartographer Light uses 4 to jettison the fairings and 5 to toggle its own engine.

iv) Flight

Although this carries the SatStack as payload once in space it can't launch by itself. Flights are discussed in the next section.

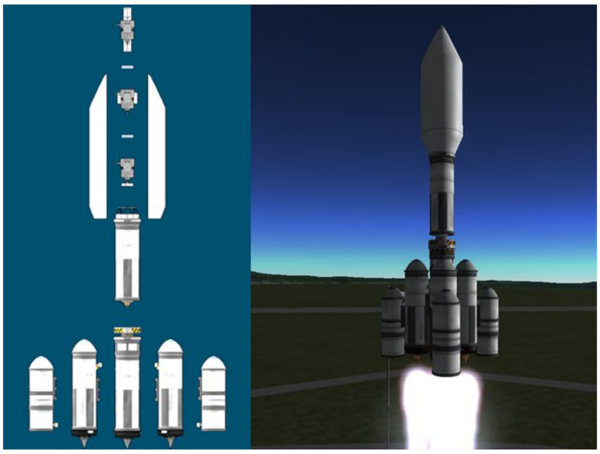
v) Notes

A deltaV map is an essential tool once you venture beyond Low Kerbin Orbit (LKO). The only important thing for space-only operations is the deltaV requirement. TWR can be very low compared to launches; it will become significant again when we discuss landings in the next chapter.

It took 3 48-7S engines to launch a single satellite in the previous chapter, now we have 3 satellites and a single engine to transfer to 'almost' anywhere – getting to orbit really is that hard! This is almost entirely due to the TWR requirement.

The separation of vehicles/stages into (Kerbin) launch, (space) transfer and (mission) payload enables you to build general-purpose transfer vehicles just as we are now starting to develop general-purpose launch vehicles. Payloads themselves may be designed in several stages but the point is that every 'lower' vehicle should endeavour to be independent of any feature of the upper ones, except their mass.

SECTION 9: LV-6-O



LV-6-O + Cartographer Light Launch

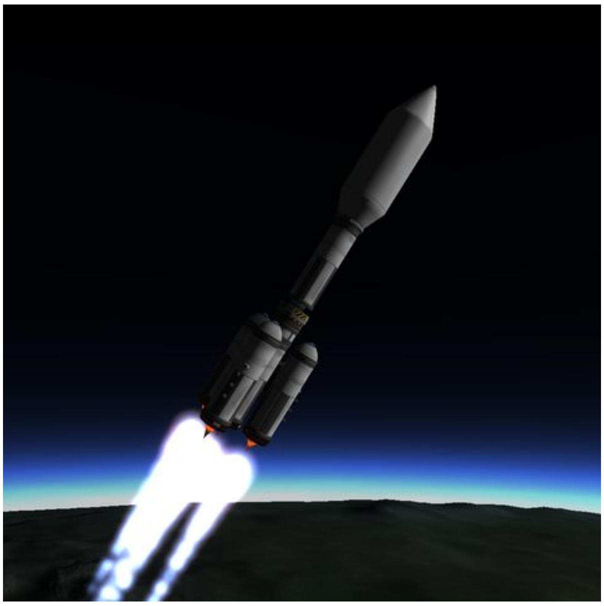
i) Data Sheet

Identity	LV-6-O – launch vehicle
Purpose	Kerbin launch. 6 tonnes.
Statistics	35.217t VAB/9.718t dry, 36 parts, cost 35,065
Design	3 onion-staged with symmetry 3. An extension to LV-2-O above.
Construction	TR-18A stack decoupler, RC-001S RGU, Inline reaction wheel, Fl-T100 and FL-T800 fuel tanks, aerospike engine. 3 x radial decouplers, Fl-T800 fuel tanks, aerospikes, nosecones and fuel-lines. 3 (more) x radial decouplers, Fl-T400 and FL-T200 fuel tanks, nosecones and fuel-lines.
Action Groups	abort:shutdown engine, 3:engines
Performance	(Kerbin) TWR 1.74, 8,816m/s

There is a simple convention to the names of my launch vehicles: LV-<designed payload mass>-<staging strategy>. Thus LV-2-O was designed for a 2 tonne payload and used onion staging. This uses the same staging strategy but is designed for 6 tonne payloads. Unsurprisingly, that's enough to launch Cartographer Light complete with a SCANSat stack.

NB: Although pretty efficient this design illustrates a number of problems that would prevent most people from using it.

ii) Construction


LV-6-O + Cartographer Light 2nd Stage

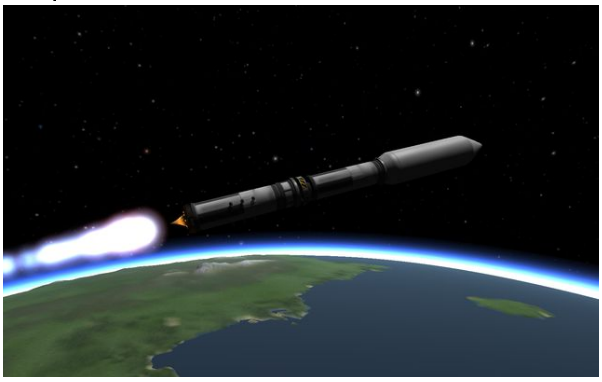
The core stage is the same as LV-2-O except that I've added an inline reaction wheel. It is not strictly necessary while launching Cartographer Light but as payloads become heavier and possibly more unbalanced they can handle sluggishly during the gravity turn or, alternatively, flip over and become unflyable. In space you may find it difficult to turn heavier rockets to face the desired direction. Reaction wheels help to stabilise or turn a rocket by increasing the torque available to SAS (provided by command pods and cores). The 'Inline Advanced Stabiliser', 'Inline Reaction Wheel' and 'Advanced SAS Module, Large' all function in a similar way – using electricity to provide extra torque – and you should consider the different costs, masses and performance figures in choosing which, if any, to use. You may add several IAS/IRW/ASAS units to a ship for increased response.

More power is required for this design and the aerospike is the optimal engine, thanks to its fuel-efficiency (high ISP) and fairly good thrust. Four, with the necessary fuel to reach orbit, give a good launch TWR of 1.74, so the most sensible 'onion' arrangement is core + 3 boosters, unlike the 2 boosters used in previous designs. Most people would consider that this results in a fairly slim, aerodynamic and aesthetically pleasing rocket (not illustrated but similar to the 2nd Stage picture). There is a lot of fuel to carry in the core and each of the boosters, however, and we can improve the efficiency by moving this to a second, outer, onion 'layer' (as illustrated in the launch picture). Note that the fuel-lines run from the outer layer to the inner and from the inner to the core. At launch, then, all the engines will take their fuel from the outer tanks until they are depleted and jettisoned. This means those tanks are jettisoned as soon as possible, the rest of the vehicle therefore doesn't need to carry their extra mass for long and, overall, needs less fuel and is thus lighter for the same payload.

No extra thrust is required so the outer layer consists of fuel tanks without engines, known as 'drop' or 'slack' tanks. In other circumstances it may be useful to also add additional early-jettison engines for initial launch thrust. In general, radial, parallel and onion staging can be taken to as many layers as you wish and more is, roughly, more efficient but there are several problems. First, you may just find your rocket falling apart on the launch pad because the joints between layers are not strong enough to support the outer ones. If it survives that the 'shear' force between layers/stages that have different TWRs may tear the rocket apart during launch. Thirdly, while drop tanks have been a common feature of long-range aircraft for many decades, the use of fuel-lines in this way is generally unrealistic and multiple layers is unaerodynamic. Finally, and for some people fatally, your vehicles start to take on an ugly 'pancake' aspect. EAS-4 struts can help with the first two of these issues; how important the other two are is up to you. As a rule I try to keep my designs to core + 1 layer, although that layer may contain more than 3 boosters, as will be shown.

An additional problem with symmetry 3 has nothing to do with structural integrity, realism or aesthetics but is, unfortunately, an artefact of computers and, in particular, the Unity engine used by KSP. Rotation (pitch and yaw) are worked-out in 2-dimensions by the game itself and it sometimes has trouble with symmetry-3, which it can't apportion equally. This can lead to unwanted spin (roll) in the third dimension due to rounding and other errors. In practice this is not something I've had trouble with but have been warned about by Vanamonde and other people who have played KSP for a number of years. (Both the lunar-landers in the next chapter use symmetry-3, if only slightly).

iii) Staging And Action Groups



LV-6-O + Cartographer Light 3rd Stage

As with all vehicles; abort shuts-down the engines while Custom03 (3) toggles them. Staging simply jettisons the drop-tanks when they are depleted and the boosters when they, in turn, are exhausted.

iv) Flight

Assemble this vehicle with Cartographer Light as its payload (with a SatStack as Cartographer Light's payload) for each of these missions. Launch into a 75km, equatorial orbit, staging as required, jettisoning the fairings and deploying the solar panels above 69km and separating Cartographer Light once circularised in orbit. De-orbit the final stage of LV-6-O.

MISSION 16: Mun

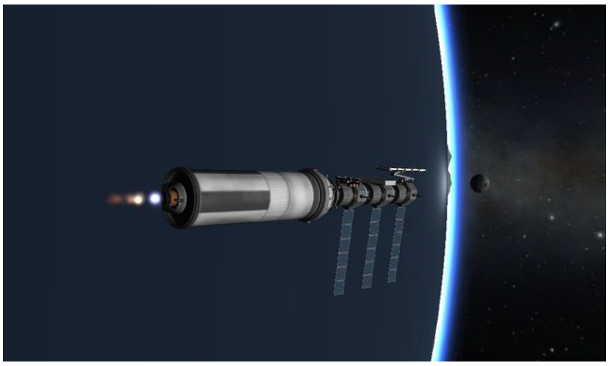
Using Cartographer Light's engine initially make sure you have a 0-degree inclination orbit. Create a (prograde) 'transfer burn' manoeuvre node to increase your apoapsis to Mun's altitude (11,400km) and drag it around your orbit so that you get a Mun encounter. Read the tutorials on going to Mun and fine-tune this as you wish. Execute the burn and fine-tune again if required for a 750km polar periapsis above Mun.

Once Cartographer Light crosses to Mun's Sphere Of Influence (SOI, you might want to time-warp to get there) have another round of tuning your orbit. The further away you can perform these manoeuvres the less deltaV they will take, which is why you should do a first round right after your transfer burn. Circularise when you reach periapsis (time-warp again as you wish) and you are now in the correct orbit to stage, place and activate the SCANSat High satellite. Perform a Hohmann transfer to a 250km orbit (at apoapsis burn retrograde to lower your periapsis to 250km then circularise at that, new, periapsis), stage, place and activate SCANSat Mid. Repeat for SCANSat Low at between 8 and 10km, any lower and it might fly into a Mun mountain!

This leaves Cartographer Light without any solar panels and fast running-out of electricity but it doesn't matter as it has completed its mission of delivering the satellites. De-orbit it so it crashes into Mun to dispose of the debris. If there is any left you can terminate it in the tracking station.

Congratulations again! Your first orbit around a body other than Kerbin and your mapping of Mun is underway. Soon you'll be able to select a flat and, preferably, interesting place to land!

But was this a good way to deliver the satellites? I've described using the transfer vehicle to place them in their correct orbits because it has lots of fuel that wouldn't otherwise be used. You're not really likely to use the satellites' fuel now either but at least it is where it *might* be needed, on operating vehicles. What about the order in which they were placed though – is low, mid, high any better or worse? Before you go to Moho you ought to find out – the requirement for orbiting around that is a bit more substantial.


Cartographer Light Transfer To Mun

MISSION 17: Minmus

Placing satellites around Minmus is very similar to around Mun but requires that initial plane change – set Minmus as your target and burn (anti)normal at AN/DN as required. This is easiest after launching to a normal equatorial orbit, before the transfer burn. On the other hand it is most efficient to launch into the correct plane in the first place, if you can. Plane-changes are most efficient with a high apoapsis, as you may have tested, so intermediate between a perfect launch and plane-change in LKO you might try raising your apoapsis very high (to the edge of Kerbin's SOI), plane-changing there, dropping apoapsis to get a Minmus encounter and then circularising into orbit as before. You can also include the plane-change in your transfer burn with a bit of fiddling-around. For me, it's more trouble and time than it's worth as Cartographer Light has enough fuel to do it the easy but inefficient way.

MISSIONS 18-25: Interplanetary

Deep space; interplanetary if not interstellar anyway. You may be fearing or looking-forward to this step; it's a long way. It also takes a long time but isn't much more complex than going to the moons. In any case you can't just go whenever you want to, Kerbin and your target have to be aligned properly first. To find out when that will be check the interplanetary tutorials, refer to KER, MJ and/or VOID and other mods and check:

alexmoon.github.io/ksp/ - or install a transfer window planner mod (included in MJ)

Your targets are Ike (Duna's moon), Duna itself, Eve, Gilly (Eve's moon), Dres and three of Jool's moons; Tylo, Vall and Pol. For the moons you will first have to get an intercept to the parent planet and then adjust, possibly within the planet's SOI. You may also prefer to postpone visiting Jool with this light vehicle and use Cartographer Heavy instead.

The general (easiest) routine is, at the correct time, burn to escape Kerbin's SOI – retrograde to Kerbin's orbit for the inner planets, prograde for the rest – then perform a plane-change and fine-tune in interplanetary space (i.e.; at the AN/DN with the target planet), fine-tune again after entering the 'alien' SOI and finally circularise around your target planet or moon. Lots of time-warping will be required unless you like staring at space for (real) months or years. It is best to continue with Kerbin missions from the next chapters while waiting for the transfer windows to other planets/moons and while the missions are en-route. This is when the Kerbal Alarm Clock (KAC) mod becomes really useful – use it to set alarms for all the manoeuvres for the many vehicles you may have in flight. It can be a little frustrating* to have a several-year mission lost in space because you forgot to circularise its orbit 5 minutes ago, for instance.

[* This is known as English understatement and means, in fact, you may well want to swear and throw things at you computer, or your computer out of the window, if it happens. KAC can save you money!]

v) Notes

This is the most efficient launch vehicle so far, with a good 15% payload ratio. Another problem that has not been mentioned though is part-count and lag. Fully-prepared LV-6-O with Cartographer Light and the SatStack is 66 parts. That's almost the most that low-end computers can cope with without starting to lag (100 starts to annoy most computers). Sometimes efficiency may not be the most important goal in your game.

CHAPTER 5: PROJECT TENACITY

Lunar Landings, Interplanetary Satellites And Docking

SECTION 1: PROJECT BRIEFING

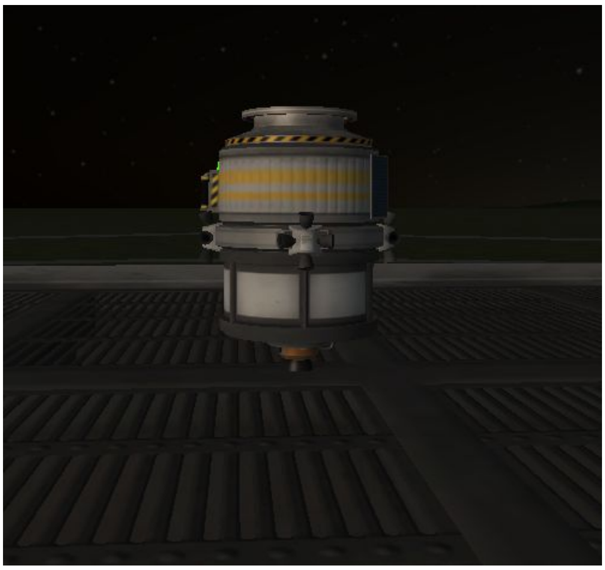
Identity	Project Tenacity – Complex Space Operations
Background	The historic moment has now come to attempt to land on Kerbin's moons. While this can be done with simple one-man missions we also wish to prepare the way for more complex – and distant – operations by developing our ability to rendezvous and dock vehicles in space. Meanwhile, our satellites can complete their mission to map the entire system, reaching even the hardest destinations.
Objectives	1) Practice rendezvous and docking in orbit. 2) Land Kerbals on each of Kerbin's moons *and return them safely!* 3) Send SCANSat satellites to the rest of the system.
Payloads	Docking Drone, Long Tom, Fat Sally, SatStack, Cartographer Heavy.
Vehicles	LV-2-O, LV-6-S, LV-8-A, LV-10-1.
Execution	A docking-drone launched on our existing LV-2-O suffices for practice. Landings require some refinements to the Orbiter payload to enable it to land-on and return from the moons. In addition they need the addition of transfer stage(s), in the same way the satellites use Cartographer Light. Cartographer itself can easily be enhanced to carry satellites to any planet or moon in the system. Suitable launch-vehicles are obviously also required, as always.

As in the previous chapter, these objectives are separate but all contribute to the continued development of KSC's abilities. Rendezvous and docking are not required for the other missions in this chapter but now is the time to practice these skills; they will be necessary for the future and are not things most people learn easily. Landing on the moons is also likely to require practice, as you can't just parachute the pods down as on Kerbin itself. The actual space-flight parts of these missions (getting to and returning from the moons, harder interplanetary) will come as light relief in comparison.

Rendezvous, docking and landing are probably the most demanding skills to learn, in KSP and real-life. Practice!

I hope that getting to orbit, flying a spaceplane and sending satellites to other planets has given you a real sense of achievement and progress in KSP. In any case the orbital dockings, lunar-landings and total satellite coverage of the system covered in this chapter certainly should. This goes somewhat further than the limits of real-life space missions, after all, in that we don't have permanent satellites around all the planets in the real solar-system. This also represents the completion of the 'beginners' section of the tutorial; once you have mastered all these skills any mission is just a matter of scale. The vehicles and missions in the rest of this campaign look at building an *efficient* infrastructure throughout the system but are more suggestions and recommendations for intermediate rocket scientists.

SECTION 2: DOCKING DRONE



Docking Drone Payload

i) Data Sheet

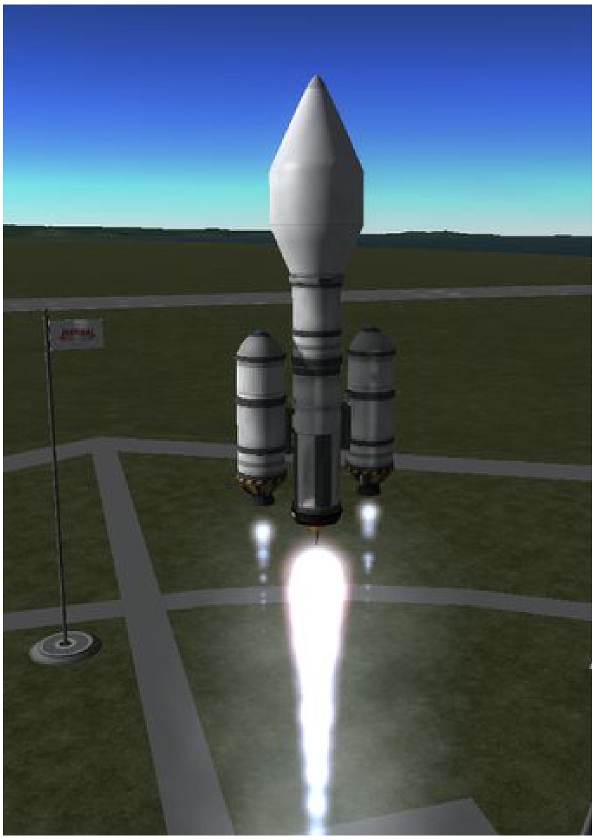
Identity	Docking Drone – payload
Purpose	Unmanned rendezvous and docking practice.
Statistics	1.962t VAB/0.463 dry, 11 parts, cost 5,860
Design	These drones use the same fuel-tank/engine combination as the Orbiter so they can manoeuvre and rendezvous in space. It is possible to dock using main engines but not usually practical, so RCS fuel and thrusters are included, as on Orbiter Mk2. The only other things are the required probe core, battery and solar-panel and, obviously, a docking port.
Construction	RC-001S RGU, FL-T100 fuel tank and 48-7S engine. FL-R25 RCS fuel tank, symmetry-4 RV-105 RCS thruster blocks. Single Z-100 battery, OX-STAT solar panel and Clamp-O-tron docking port.
Action Groups	abort:shutdown engine, 6:engine
Performance	(Vacuum) TWR 2.24, 1,011m/s

ii) Construction

This is a simple drone that is simple to build. The only thing to watch out for is that the RCS thruster blocks should be around the CoM for balance. The problem with that is that the CoM will move up/down quite a bit depending on the relative amounts of liquid fuel/oxidiser and RCS fuel that you use. In any case these drones are very lightweight so agile so should be as easy to use as any space-vehicle can be.

iii) Staging And Action Groups

Abort shuts-down the engine and Custom06 toggles it, that's all.



LV-2-O + Docking Drone Launch

iv) Flight

Launch docking-drones using the LV-2-O vehicle from the previous chapter (with appropriate fairings and base if using Procedural Fairings). Don't forget the decoupler!

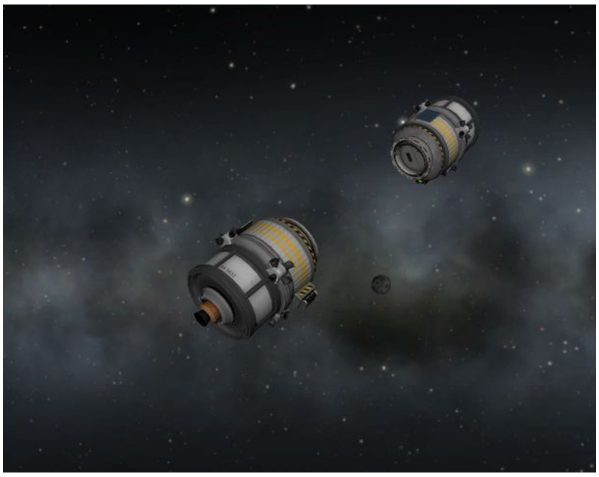
MISSION 26: We Meet Again

Launch two docking drones to orbits of different heights so their orbital-periods are different. This ensures that (eventually) they will come into alignment such that a Hohmann transfer from one orbit to the other will bring them together. Launching the first to, say, 150km and the second to 75km means the second will 'catch up' with the first after a number of orbits. Switch to whichever drone you decide to control then click the other in map mode and 'set as target'.

When you perform the Hohmann transfer and come close to the target ensure that your navball is showing the relative speed; target mode, click on it to cycle through the options. Bring your drone to a halt, relative to the target, within a few kilometres initially, then approach slowly, possibly in several steps, keeping your relative speed below around 10m/s per kilometre distance, stopping again within 100m, or so.

Docking requires aligning the docking-ports and bringing them together at low speed. Once they are close enough (1 or 2 metres) their magnets will automatically engage, draw them together the rest of the way and complete the docking. Use RCS for docking (H/N=forward/back, I/K=up/down, J/L=left/right), rather than main engines. Several things can make this easier:

1. Light vehicles will be affected more by the magnetic locks on the ports, meaning you can be less precise in alignment. These drones being under 2 tonnes makes them particularly easy to dock. By extension, however, you will find heavy vehicles generally harder so practice first with these!
2. Avoid having to fly 'around' the target after rendezvous by facing the docking-port at the target and then switching vehicles. Turn the target so its port faces the incoming vehicle – they are now both 'almost' aligned already. Again, this will be harder with heavier, more unwieldy vehicles but the drones make it simple. Hold the 'target' steady by engaging its SAS.
3. As a rule (which should therefore be broken whenever you find it easier) you should dock the lighter vehicle to the heavier, as it will be more manoeuvrable and fuel-efficient. Once rendezvoused control whichever you prefer and call the other 'target'.
4. Use the navball, low speeds and, preferably, a docking-alignment mod. In many cases the only reason you'll need to look at the ships themselves, if at all, is to check your separation, the navball will tell you everything else.
5. Aim to come to a stop with your docking port about 5-10m 'in front' of the target port and perfectly aligned (within a few centimetres, if you have a tool that will tell you that), then thrust forward to come straight-in, slowly!, until the magnets engage.
6. Turn off SAS and RCS, preferably on both vehicles, once in this last stage or they'll tend to fight any minor adjustments the magnets cause.



Docking Drones Docking

v) Notes

Read/watch as many rendezvous and docking tutorials as you can cope with. Go slowly. Be patient. Practice.

Fairly obviously, if you stop your Orbital speed you'll fall out of the sky! Keep the navball in 'target' mode once close enough, and make sure it's *relative* speed you're changing.

Don't forget that you don't need to do this for the other missions in this chapter. If you are getting frustrated – or bored; rendezvous and docking can take a lot of time – carry out some other missions here and come back to rendezvous/docking when you can face it. (If you *really* have trouble, you can use MechJeb's autopilot for rendezvous and/or docking).

Once docked together ships act as a single vehicle. That means you can transfer fuel between tanks by (alt-)right-clicking them. Orbital refuelling is coming.

SECTION 3: LONG TOM

Long Tom Payload

i) Data Sheet

Identity	Long Tom – lunar payload
Purpose	Manned lunar landings
Statistics	4.72t VAB/1.888 dry, 21 parts, cost 6,705
Design	4 serial-staged: transfer, landing, return and recovery
Construction	Command pod Mk1, Mk16 parachute, OX-STAT solar panel, BTDT sensor (SCANSat). TR-18A decoupler, Telus LV ladder, 3xROUND-8 and 1xFL-T100 tanks, 48-7S engine, Z100 battery. TR-18A decoupler, FL-T100 tank and 48-7S engine, 3xLT-1 landing legs. TR-18A decoupler, FL-T200 and FL-T100 tanks, 48-7S engine.
Action Groups	gear:legs and ladder, brakes:parachute, abort:shutdown engines, 4:transfer eng, 5:lander eng, 6:return eng, 7:instr
Performance	(Vacuum) TWR 0.65, 3,150m/s (return Mun landing, Duna orbit)

When designing the Cartographer Light transfer vehicle in the previous chapter it was necessary to consider the deltaV required to reach and orbit each body in the system; we now also have to add landing. For simplicity I assume that the second half – re-launch, re-orbit and return – are the same as the first. In practice re-establishing orbit around a moon is not necessary before returning, if you time your launch right, and for the return you can save deltaV by aerobraking in Kerbin's atmosphere. Unless you are using the DRE mod you can even launch straight from a moon to a dustdown/splashdown landing on Kerbin if you want (trying that with DRE you'll just burn-up on re-entry!).Referring to the deltaV map again:

"How hard is it to transfer to, orbit then land (from Kerbin LKO, m/s)?" table

Minmus	1,610
Mun	Long Tom - > 1,750
Ike	Fat Sally - > 1,940
Gilly	2,980
Duna	3,000
Pol	4,170
Dres	4,290
Vall	4,750

Eeloo	5,410
Tylo	6,130
Bop	6,140
Moho	7,510
Laythe	7,560
Eve	14,880

(Jool & Kerbol N/A)

Note especially that although it is easier to go to Mun than Minmus (previous chapter), it is so much easier to land-on and take-off from Minmus once you get there that, overall, this is the simpler mission. Minmus also has large, flat areas meaning that it is strongly recommended that you make it your first target for landings.

This vehicle, Long Tom, is capable of Minmus and Mun landings. A 'better' lander, Fat Sally, is presented below (section 5) and is even capable of landing on and returning from Ike, Duna's moon. Such a mission is not detailed here because it seems unrealistic to send a single Kerbal unsupported on such a long voyage. It shows how capable small vehicles can be though (and we're still in the realm of 'small' here) and you should have the necessary interplanetary skills as well, from using Cartographer Light. Should you be feeling cruel and don't care about getting your Kerbals back Long Tom and Fat Sally can both get manned missions to Duna. There's not much point though as you'll be visiting that and more, unmanned, with the Cartographer vehicles and the last two chapters of this campaign will be manned to everywhere.

It is not possible to land on Jool (a gas-giant with no 'ground') or Kerbol (the sun, are you mad?!).

ii) Construction

LV-6-S + Long Tom Launch

Long Tom is a complex vehicle, designed in four separate stages. Cartographer Light had that many but three of them were the virtually-identical satellites. Here, each stage has a distinct purpose and must be considered separately, from top to bottom as they will appear in the final design.

1) Kerbin Recovery Stage: All that needs to return to Kerbin is the command pod. For that to happen safely, it'll need a parachute. I've also put the solar panel and BTDT sensor on this stage as they look a bit more aerodynamic here than on the lower stages. Ah well, every design is a compromise in practice. As with Orbiter you can tweak the monopropellant out of the command pod to save a little mass, as this vehicle will not dock. Done.

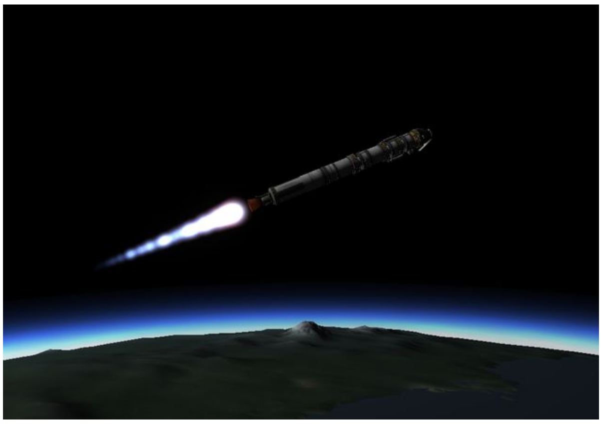
2) Return Stage: To get the recovery stage from the surface of Minmus back to Kerbin will need 1,610m/s deltaV, 1,750m/s from Mun (from table above). The payload mass (recovery stage) is 0.935t plus a decoupler, ladder so our Kerbal can reach the surface and return while we're landed on the moons and a battery to supplement the pod's power. Using the trusty 48-7S engine we need a bit less than 90 units of fuel for this so I have used an FL-T100 and three ROUND-8 toroidal tanks (you may just use an FL-T200 tank if you prefer). Done.

3) Landing Stage: Actually landing on Minmus/Mun will require 180/580m/s. An FL-T100 and (another) 48-7S is sufficient, even with the decoupler and landing-legs, to give 643m/s. Although this is more than we 'should' need it provides a margin-for-error so I do not recommend reducing it. Done. You can use a more conventional-looking 4 legs if you prefer but the extra one will add mass. While it is possible to land without legs it's important to keep the vehicle upright after landing so you can lift-off again! Some people prefer to build a stable base for landers using cubic octagonal struts – it's up to you.

4) Transfer Stage: Before any of that can happen Long Tom has to get everything from LKO to the moon and, for an easier landing, into orbit around it. From the Cartographer Light flights we already know that'll take 1,430m/s for Minmus and, with yet another decoupler and 48-7S engine, that'll take an FL-T100 and an FL-T200 fuel tank. Finally done!

All-up Long Tom is 0.8t lighter than Cartographer Light, with comparable payloads (0.94t command pod + parachute versus 0.774t satellites + fairings). It could be made lighter still by reducing the margin-for-error on each stage and, possibly, by splitting the return stage even more. In some ways though Long Tom takes the idea of designing a vehicle-stage for each mission-stage too far. Fat Sally, later, is both simpler and more capable. This method of design has the great advantage of clarifying requirements to you though.

iii) Staging And Action Groups



LV-6-S + Long Tom 2nd Stage

Staging separates Long Tom into its constituent mission parts – transfer (from LKO to Minmus/Mun), landing, return and recovery – at each of the decouplers.

The action groups follow my standard format, with the ladder being added to the (automatic) gear group, brakes being used for the recovery parachute and abort shutting-down all engines. Custom04-06 toggle the engine of each stage in turn, with 7 toggling the SCANSat BTDT sensor, if you are using it.

iv) Flight

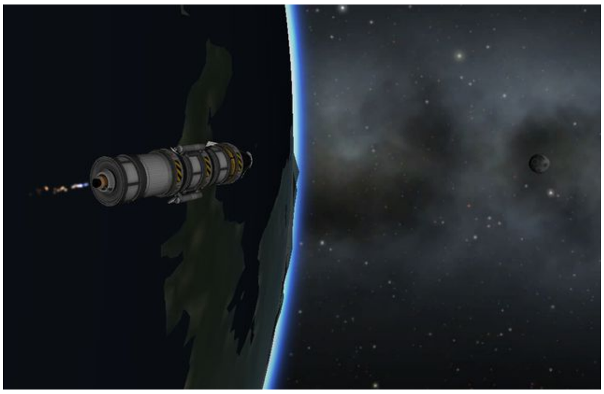
Long Tom is a transfer/payload vehicle. Flights are discussed in the next section.

v) Notes

Designing your vehicles in several stages, carefully thinking-through what each stage has to achieve, gives you a good feel for what you do and don't need at each point. Work backwards, keeping everything as light as possible as anything excess to requirements will have a big knock-on effect as you design 'lower' stages.

Aerobraking can save a lot of deltaV.

SECTION 4: LV-6-S



Long Tom Transfer Stage

i) Data Sheet

Identity	LV-6-S – launch vehicle
Purpose	Kerbin launch. 6 tonnes.
Statistics	39.15t VAB/11.15 dry, 12 parts, cost 24,700
Design	2 serial-staged.
Construction	TR-18A decoupler, RC-001S RGU, FL-T400 and FL-T800 tanks, LV-T30 engine. TR-18A decoupler, inline reaction wheel, Rocomax brand adapter, Jumbo-64 fuel tank, Skipper and 2xMark 55 radial mount engines.
Action Groups	abort:shutdown engine, 3:engines
Performance	(Kerbin) TWR 1.85, 8,639m/s

ii) Construction

Memo: "The oversight committee are concerned at the cost and complexity of our last launch-vehicle. Construction problems and launch failures are exacerbating expenses in parts, VAB overtime, quality-control and insurance budgets. Please phase-out LV-6-O in favour of a simpler, more reliable design."
Von Kerman: "Vell, ze oversight committee are just zis bunch of guys, you know. LV-6-O is our most efficient design."
Jeb: "Moar boosters!"
Bill: "y u mk rocktz hrd, mk it eze cuz they r hrd"
Bob: "A few larger, more robust, parts could result in a simpler, more stable vehicle"
Von Kerman: "Hmmm, ze LV-T30 is a basic und zehr gut engine ve haff not used. Zis vill be our new final stage to orbit."
Fred: "'Ere mate, I've got this deal with Rocomax for a Skipper engine and orange tube of fuel to shift it all off the pad."
Memo: "Stop messing around and get on with it! Kerbalkind wants to see a Kerbal on Minmus ASAP."

The T30 is a great basic engine with more thrust than the aerospike but not quite so good ISP. One of the big advantages of the T30 is that unlike the aerospike you can attach a lower-stage beneath it. A T30 with the fuel detailed in the data-sheet is a good launch-vehicle for light payloads in its own right and makes a good, if somewhat over-powered, upper-stage for this one. Career-mode players start with the T30 and know how good it can be but usually overlook it in later designs, thinking later engines must be better. This just shows why career-mode is, currently, not a good way to learn how to design rockets.

In order to minimise part-count the lower stage of LV-6-S is built around the Skipper engine and largest 2.5m fuel tank, the Jumbo-64 or 'orange tube'. An inline reaction wheel is included for stability and the Rocomax adapter for aerodynamics/aesthetics. On its own the Skipper can't really lift all this efficiently (launch TWR 1.24) so is assisted by the pair of Mark 55 engines. The choice for radial-mount engines is very small but these are a good high-ish thrust choice.

Note that Long Tom on top of LV-6-S really is long – you will need EAS-4 struts (as illustrated) to stop the whole lot wobbling out of control.

iii) Staging And Action Groups

The three lower-stage engines in stage 2, decoupler and upper-stage engine in stage 1, payload decoupler in stage 0. Action groups to shutdown or toggle engines – it's not rocket science!

Oh, wait a minute; it IS rocket science, but that doesn't mean it has to be complicated ^^.

iv) Flight

Launch Long Tom to standard LKO on top of LV-6-O or LV-6-S as you prefer, or use a different one for each mission and compare performance; another benefit of modular design. Practice these landings without crew if you care for your Kerbals!

MISSION 27: One Small Step

Long Tom Lander Stage

You should already know how to get to Minmus from using Cartographer Light. As Long Tom is not as heavy as either launch-vehicles' designed payloads they will have enough fuel left to perform the required plane-change, saving fuel in the later stages. You may even use them to start the transfer burn (they won't have enough fuel to complete it) but that probably means leaving them as space-debris, unless you terminate them in the tracking station.

Unlike Cartographer Light and the SCANSat satellites you want to place Long Tom in an equatorial, preferably Eastward (anti-clockwise), orbit around Minmus. This is because that is the way the moons rotate and, just as on Kerbin, you can use the surface rotation-speed to your advantage; a slightly reduced deltaV requirement. Your target altitude should be 7-10km, although you may prefer to circularise higher than that initially and then Hohmann transfer to the lower orbit.

Remember that Long Tom only has a single fixed solar panel, not the multiple 6x1 sun-tracking ones of Cartographer Light/satellites. Make sure you orient it after each manoeuvre to keep the battery charged. You should be able to establish this low orbit without exhausting the transfer-stage fuel, in which case use it when you start your landing.

Select a landing site on the daylight side of the moon, under or near your orbital path (or you'll have to plane-change again). If possible, aim for one of the large, flat 'frozen lakes'. Quicksave before starting to land. Read-up on landing tutorials; the easiest way is to keep your navball heading indicator on the retrograde marker. Aim to touch down at less than 10m/s vertical speed and with almost no horizontal movement. Note that Minmus's gravity is so low it is quite easy to accidentally start ascending again, use low throttle! Jettison the transfer stage when it's spent or before touching-down in any case. Extend the landing legs! If you aren't using SAS already, engage it once you touch-down so that the vehicle doesn't tip over. You may well bounce off the surface a short way – SAS will help with that too. Quickload and try again if it all goes wrong. Practice!

Once landed... breathe, you might have forgotten to in the last few minutes.

Let the bells ring-out across Kerbin! A Kerbal landed on a moon! Really, if you don't get a sense of satisfaction from your first manned landing there's no pleasing you. Then calm down, a bit, because there's more to come. With the eyes of every Kerbal glued to their television sets (whatever they are) it's time to EVA your pioneering astronaut, climb down the ladder and set foot on alien soil. Plant a flag (right-click your Kerbal) and say something memorable. Tell someone all about it :-) Take screen-shots and post them on the forums if you want to tell us about it :-)

Party!

While your Kerbal is out there: you might want to walk around a bit, he'll bounce a lot in the low gravity. Hold shift while pressing the direction keys to make him run, press space to jump – high! Press R to activate the spacesuit RCS pack and have a fly around. It is even possible for your Kerbal to reach orbit again, just on RCS. This is not recommended though, the command pod is a bit handy for getting home.

When you're ready to come home: guide your Kerbal back to the ladder (may have to jump/RCS), climb up to the command pod and re-board it, retract the ladder. You should still have fuel in the lander stage, in which case you can use it to start re-orbit (10km, 0-degree inclination), jettison it once used-up. Then perform your return-burn and fine-tune for Kerbin. Back in Kerbin orbit, proceed with de-orbiting and landing as for Orbiter.

To a hero's welcome.

(Although I recommend using Fat Sally for Mun landings you may want to try a Mun landing with Long Tom, which is certainly capable of it. Getting there is easier, of course, but it's harder to land because of the higher gravity AND it can be difficult to find somewhere safely flat – do the best you can. If Long Tom falls over on landing and your Kerbal survives but is unable to come back you'll have to launch a rescue mission – perhaps using an unmanned Fat Sally – or just Quickload and try again).

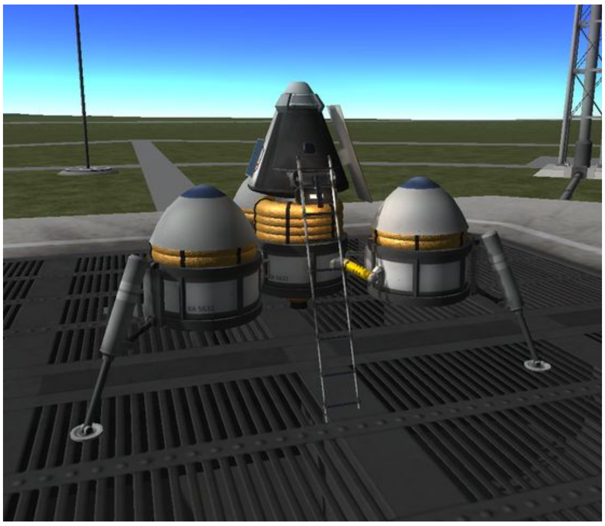
v) Notes

Long Tom Return Stage

This launch vehicle is designed for the same payload-mass as LV-6-O in the previous chapter and, unsurprisingly, has similar performance. It's here mainly because it provides a direct comparison of staging design strategies and partly because I like role-playing the hassle that the 'oversight committee' generates! Ignore this vehicle if you wish, you should note, however:

- Efficiency: This serial-staged design is heavier than the onion-staged one, so has a much worse payload-ratio.
- Part-count: In contrast onion-staging has more parts, so is more likely to cause your computer to lag (run slowly).
- Construction: With fewer parts and simpler construction the serial-staged version is much easier to build...
- Reliability:... And less likely to fall-apart on the launch-pad or in flight.
- Realism: Many KSP players seem to think serial-staging is almost the only real way to design a rocket. FAR aerodynamics make it almost a requirement.
- Cost: Serial-staging is also more than 10k cheaper.
- Neither design is fully optimised and either could be improved in several ways. You should experiment with your own designs, optimising for whichever of these factor(s) suit how you want to play the game.

SECTION 5: FAT SALLY



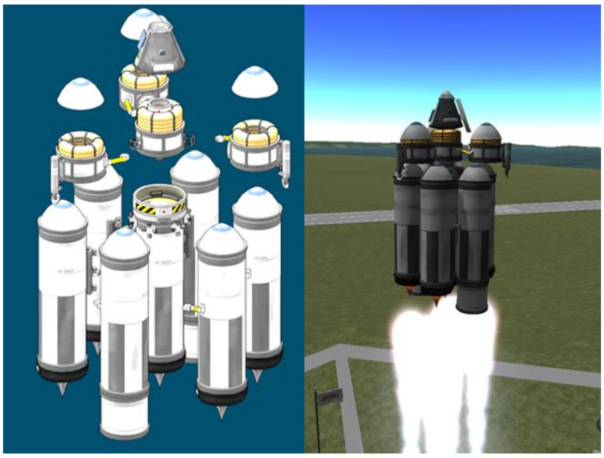
Fat Sally Payload

i) Data Sheet

Identity	Fat Sally – improved lunar payload
Purpose	Manned lunar landings
Statistics	4.955t VAB/1.845t dry, 38 parts, cost 10,488
Design	3 onion/serial-staged: transfer, return, recovery.
Construction	Command pod Mk1, Mk16 parachute, OX-STAT solar panel, BTDT sensor (SCANSat), telus LV ladder. TR-2V decoupler, 4xROUND-8 and 1xFL-T100 tanks, 48-7S engine. 3 x cubic octagonal struts, TR-2V decouplers, FL-T100 and 2xROUND-8 tanks, LT-1 landing legs, fuel lines, decouplers and nosecones.
Action Groups	gear:legs and ladder, brakes:parachute, abort:shutdown engine, 4:nosecones, 6:engine, 7:instr
Performance	(Vacuum) TWR 0.63, 4,016m/s (return Ike landing, Duna orbit)

Fat Sally is a better, but heavier and more expensive, lander than Long Tom. Some design-optimisation 'tricks' are used.

ii) Construction



LV-8-A + Fat Sally Launch

Fat Sally was designed too late for the original Minmus mission but is an attempt to address Long Tom's tendency to fall over on slopes. Critically, the important features of a lander should be low CoM and wide leg-base, neither of which Long Tom has. At the same time it was decided to see what design optimisation was possible in order to remain under 5t while including more fuel, either as a greater margin-for-error or to allow Fat Sally to carry-out more complex missions.

The recovery stage of Fat Sally is essentially the same as Long Tom's except that the ladder has been moved up onto the pod itself. This is because the TR-18A decoupler has been replaced with a TR-2V, saving 35kg. The TR-2V works perfectly well even if it is the 'wrong' size so why waste the mass. Remember, every 100kg saved on the payload is potentially 1 tonne saved from the launch-vehicle. Little changes like this can seem silly but they add up and their knock-on effects can be enormous.

Similarly, Fat Sally's return (centre) stage is the same as Long Tom's but with one more ROUND-8, which is a consequence on dividing-up the fuel later. Using onion-staging for the rest of the vehicle keeps the CoM low, gives the necessary wide base to the landing legs and, as a bonus, keeps the core 48-7S engine clear so we don't need to add any others (saving another 0.2t over Long Tom). When considering lander engine(s) it is important that their TWR is greater than 1 for their target body, otherwise they won't be able to brake to a halt during landing – which means lithobraking (i.e.; crashing)! Landers are usually required to be able to take-off again as well, of course, so if they are intended to land on a body with an atmosphere they will ideally be able to reach the local terminal velocity.

The drop-tanks attached radially share the fuel-load with the core and feed it with the fuel-lines, hence it is onion, not radial, staged. The nosecones are just for aesthetics/aerodynamics and a bit more mission-mass has been saved by attaching them with decouplers and jettisoning them out of the atmosphere.

A little more mass is also shaved off by not using radial decouplers (0.025t each). Cubic octagonal struts are instead placed on the core stage, with more TR-2V decouplers on them. This saves 0.01t each (the struts are massless in flight) and whether it is worth it or not is up to you. I haven't bothered to use it on any of the other designs here – there are no rules that say you have to make everything as efficient as possible.

iii) Staging And Action Groups

Just like Long Tom except that there is only the one engine.

iv) Flight

Launch Fat Sally with LV-6-O or LV-6-S as you prefer. In the illustrations it is shown with LV-8-A but that's only because I didn't have an 8t payload handy!

MISSION 28: The Conquered Mun

Land on Mun and complete Kerbal's conquest of the local system. To a large extent you can land Fat Sally anywhere, although there are some cliffs it's best to avoid!

v) Notes

LV-8-A + Fat Sally 2nd Stage

Lander engines must meet the same TWR requirements as launch vehicles (for their target bodies). It would be good design practice to see just how much weight Fat Sally can lose while still being capable of return Mun landings. Similarly, test how you can make a wide, low lander with as few parts as possible. Consider the issues of launching a wide, low payload when aerodynamics, if not aesthetics, favours tall and thin (as it does with FAR, for instance).

Have you noticed that the vehicles have their ox-stat solar panel on the left? It's somewhat important, but can you tell why?

SECTION 6: LV-8-A

LV-8-A + Fat Sally 3rd Stage

i) Data Sheet

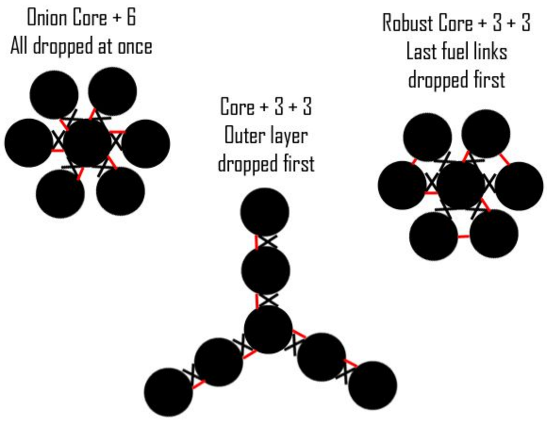
Identity	LV-8-A – launch vehicle
Purpose	Kerbin launch. 8 tonnes.
Statistics	41.73t VAB/11.73t dry, 34 part, cost 39,890
Design	4 asparagus staged.
Construction	TR-18A decoupler, RC-001S RGU, FL-T800 fuel tank, aerospike engine. 2 x radial decouplers, FL-T800 fuel tanks, aerospike engines, fuel-lines and nosecones. 2 x radial decouplers, FL-T800 and Fl-T200 fuel tanks, fuel-lines and nosecones. 2 x radial decouplers, FL-T800 fuel tanks, aerospike engines, fuel-lines and nosecones.
Action Groups	abort:shutdown engine, 3:engines
Performance	(Kerbin) TWR 2.14, 8,625m/s

Asparagus is the optimal special-case of onion-staging using symmetry 2.

ii) Construction

LV-8-A + Fat Sally 4th Stage

You have seen that staging works by using and jettisoning fuel and engines so the excess empty tank and useless engine mass does not have to be carried by the remainder of the vehicle. By using radial staging rather than serial we can have more engines working at once, by making them parallel we can use the 'core' centre engines as well, right from launch. The core then needs more fuel than the booster stages so that it can continue to burn after they are jettisoned. Adding fuel lines from the booster tanks to the core in an onion-staging strategy both uses the outer-layer fuel faster and keeps the core stage fully-fuelled. This takes us as far as LV-2-O in the previous chapter and this core + 2-booster design is very flexible and efficient over a wide range of payload mass (with different engines and amounts of fuel). With LV-6-O, however, we needed the thrust from 4 engines rather than the 3 the core+2 allows and so I simply made it core+3. For heavier designs you can, of course, proceed to core+4, 5 or 6 (more will probably not fit around the core). The drawback with core+6 is that all 6 outer-layer tanks have to be used before any are jettisoned, so the extra mass has to be carried for longer. Core+3+3, as in LV-6-O means the outermost 3 are used and discarded much earlier, with improved efficiency. Multiple onion-layers introduce their own problems though – not least of which are the physical ones of having tanks attached to tanks, attached to tanks and the wide, pancake, appearance of the rocket. A convenient solution to this is attach all the outer tanks to the core (core+6) so the rocket is thinner and more robust but to run the fuel-lines as if they were core+3, as in the diagram below. The logical, fuel, connections are the same as core+3+3 with its efficiency advantages but the physical, decoupler, connections are the same as core+6, with its structural ones – the best of both worlds. If the core is a 2.5m tank, 8 1.25m ones will fit around it and can be connected as core+4+4 in a very similar way. Thus onion is all about arranging tanks and fuel-lines with symmetry in order to maximise staging efficiency.



Asparagus staging is the special-case of onion-staging using symmetry-2. Since the whole point is to use stages as quickly as possible, and it is quicker to use and jettison 2 tanks instead of 3 (or more), this is the optimal staging strategy for mass-optimisation. We can't just use and jettison 1 tank at a time, except in the core, because it would unbalance our rocket to drop a tank from just one side; that's why symmetry-2 is the minimum and optimum. The physical arrangement maintains the robust design of 6 tanks around the core but optimises staging by linking them in an asparagus core+2+2+2 arrangement with fuel-lines. While it is possible to extend staging to additional 'layers', as in LV-6-O, just by spiralling-out it is rarely worthwhile unless you are chasing the best payload-ratio possible.

In practice it can be fiddly to attach the necessary decouplers, fuel-lines and possibly struts for asparagus staging and it uses a lot of parts. While optimal for mass-efficiency (payload ratio) you may prefer to stick with the simpler construction of serial or parallel staging. Asparagus is usually no harder to build than other onion-staging strategies though as it is only the fuel-lines and staging of decouplers that is different. The other great advantage of onion, and especially asparagus, staging is that each stage may have different, or no, engines to 'tune' the TWR in a very simple way.

For an 8 tonne payload plus decoupler and RGU the core can be formed with an FL-T800 fuel tank and aerospike engine for a TWR of 1.26. While this is low it will only be used alone for the last burn into orbit and circularisation, where raw power is not so important. Adding the first booster-stage with its 2 aerospike engines increases the TWR to 2.04 for the 'race to space' after the gravity-turn, when terminal velocity is no longer a limiting factor. For the second booster stage more thrust from more engines is not necessary and even with more fuel the TWR only drops to 1.42 so this stage is left as 'slack' or drop tanks. Finally, for the third booster stage (first to be jettisoned) more engines are again required, leaving the final launch TWR as 1.79. This is only one of several valid tank/engine-arrangements that will deliver the required deltaV to reach orbit; you may care to experiment with different combinations and different engines.

iii) Staging And Action Groups

Fat Sally Lander Stage

Action groups are the usual shutdown and toggle for all engines. Staging jettisons the boosters from outer to inner, then core from payload, in the order that fuel-lines are run.

iv) Flight

Memo: "Due to budget cuts the Duna Explorer mission has been cancelled. No further manned missions will be scheduled outside the Kerbin system until SCANSat mapping is complete".

There are no flights or missions in this campaign for this, the only really efficient launch vehicle in the tutorial (payload ratio 19.17%!). Typical, isn't it!

v) Notes

Fat Sally Return Stage

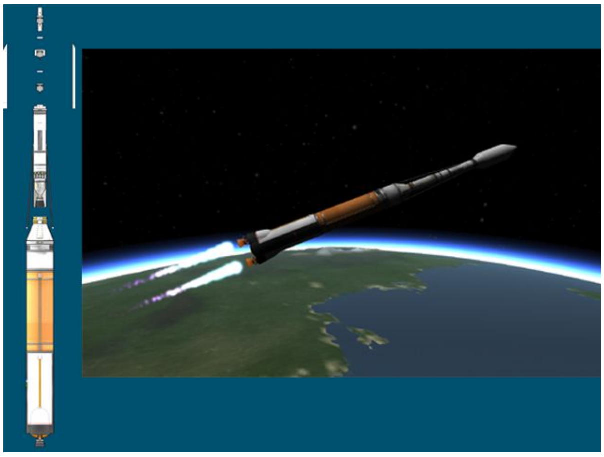
Although you will have a total of 6 decouplers around the core you need to place them using symmetry-2 so that opposite boosters will be jettisoned at the same time, maintaining balance.

While arranging all the stacks in a single line, as in the second diagram above, is functionally identical to putting them all around the core, it is structurally very weak.

Beauty is in the eye of the beholder. Some people on the KSP forums will see LV-8-A with a suitable payload as good, efficient, design. Others will see it and scream, "ugly asparagus pancake!", especially with a payload like Fat Sally which is itself wide and low. Amusingly perhaps, with a longer, thinner payload like the Cartographer vehicles those same people will see no problem. Yet other people object to asparagus not on aesthetic grounds but because the idea of infinite-flow fuel-lines passing through several layers of tank is just not realistic. Possibly that's just a difference in Kerbal and human technology but, much more plausibly, were all that fuel really spiralling-around the core (as in the robust design) in real life it would cause the whole rocket to spin an equal and opposite amount – much like a helicopter that doesn't have a tail-rotor to stabilise it. If you care about justifying this it is equally plausible that the SAS torque of the probe core is sufficient to counter the spin.

In theory there isn't really a suitable payload for LV-8-A in this campaign, as I've said. It is over-powered for 4t Fat Sally and under-powered for the 10t Cartographer Heavy below. Should you wish to try it with a heavier payload, however, you can use Cartographer Heavy's own engine to complete circularisation at LKO and should still be left with sufficient deltaV for all missions, if you fly it properly. Such are the safety-margins built into these designs.

SECTION 7: CARTOGRAPHER HEAVY



LV-10-1 + Cartographer Heavy Launch

i) Data Sheet

Identity	Cartographer Heavy – transfer vehicle
Purpose	Interplanetary satellite delivery
Statistics	9.864t VAB/3.672t dry, 28 parts, cost 23,960
Design	A simple and efficient extension to Cartographer Light
Construction	(SatStack with fairings payload), RC-001S RGU, FL-T800 and FL-T400 fuel tanks, LV-N atomic rocket motor.
Action Groups	abort:shutdown engine, 4:fairings, 5:engine
Performance	(Vacuum) TWR 0.62, 7,459m/s

ii) Construction

There is very little difference between this and Cartographer Light. This has more fuel and a better engine to enable it to reach even the hardest (highest deltaV requirement) planets and moons in the system.

The LV-N is the most efficient 'normal' engine in KSP – it has the highest Isp - but is heavy and has low thrust. As such it's not much use for launching or landing but ideal for long-distance space-travel where its mass and thrust aren't as important as its fuel-efficiency. With this we almost complete the set of engines you should consider for any vehicle:

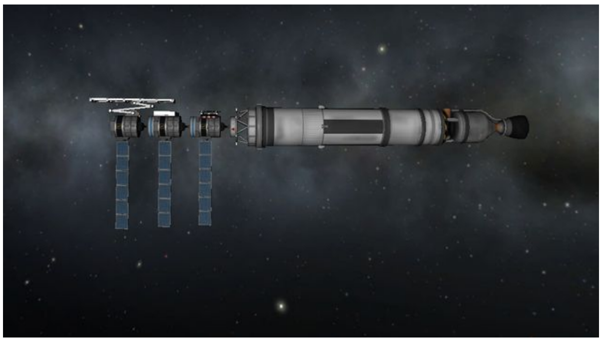
- LV-1(R) for very light vehicles, eg; satellites. Because its tiny.
- 48-7S for light launch and transfer vehicles. It has great thrust for its weight and pretty good ISP.
- Aerospikes for launch vehicles too heavy for the 48-7S. Really good ISP.
- T30s when aerospikes just don't have the concentrated thrust you need. Probably the best all-round engine.
- LV-N for transfer vehicles when the 48-7S is too weak or the LV-N's fuel-efficiency is more important than its mass. Vacuum fuel efficiency.
- Turbojets, of course, for the atmospheric stage of (space)planes. Oxygen atmosphere fuel efficiency.

Combinations of these engines, or clusters of them (eg; using bi-, tri- or quad-couplers) will give you the most mass-efficient rockets for any use. Using different engines will require more fuel and result in a heavier vehicle so from an efficiency perspective using them is a mistake, or compromise at best. As has been stressed though, mass-efficiency might not be your only, or principle, design goal. Higher-thrust engines may make a simpler, more robust, build with fewer parts, even if they are less efficient.

iii) Staging And Action Groups

Action groups are the usual for jettisoning fairings and toggling the Cartographer's transfer engine.

iv) Flight



Cartographer Heavy Transfer Stage

As with Cartographer Light we need another launch vehicle (below, unless you want to use LV-8-A above) before we can discuss flights.

v) Notes

The low thrust that an LV-N delivers means that interplanetary burn-times will be 5 minutes or more each (to escape Kerbin and circularise around your target planet/moon). With heavier vehicles that's only going to get worse and multiple LV-Ns often don't improve it much. Some people have the patience for 20-minute burns and some don't – hint: use MJ's autopilot to reduce the tedium. At the cost of reduced fuel-efficiency you can always add a few T30s just for shorter burns. Design the way you want to.

SECTION 8: LV-10-1

i) Data Sheet

Identity	LV-10-1 – launch vehicle
Purpose	Kerbin launch. 10 tonnes.
Statistics	96.85t VAB/16.85t dry, 9 parts, cost 42,180
Design	SSTO
Construction	TR-18A decoupler, Rocomax brand adapter, RC-L01 RGU and advanced SAS module, large. OX-STAT solar panel and Z-100 battery. X200-32, Jumbo-64 and LFB KR-1x2 fuel tanks/engines.
Action Groups	abort:shutdown engines, 3:toggle engines
Performance	(Kerbin) TWR 2.11, 5,839m/s

From one extreme to the other – instead of the complex efficiency of asparagus, the brute-force simplicity of single-stage.

ii) Construction

So, staging, yeah, it makes things efficient but complex. When you really want to keep it simple just use a big engine (cluster) and lots of fuel. This vehicle has a SAS module for torque and an RC-L01 so it can be controlled during de-orbit but otherwise it's all fuel for the one pair of engines. It is the lowest part-count launch vehicle in the campaign – and that's if you include the solar panel and battery, which aren't really necessary.

Just look at the picture to see how it's put together, if you need to – it's a single stack, just make sure the payload decoupler's at the top and the engines are at the bottom.

iii) Staging And Action Groups

Action groups are the usual shutdown and toggle for all engines. No staging, other than to separate the payload after circularisation.

iv) Flight

MISSIONS 29 – 33: Ubique

Cartographer Heavy can take the SatStack payload into orbit around any planet or moon. Specifically, it can reach Eeloo, Jool, Laythe, Bop and Moho, which Cartographer Light can't. Off you go.

v) Notes

Interplanetary missions take a long time. Feel free to continue operations within the Kerbin system while these missions are en-route or just waiting for a transfer window.

If you have followed this campaign so far you have:

- Learnt to control rovers, aircraft, rockets and Kerbals on EVA.
- Also learnt to rendezvous and dock vehicles in space.
- Landed a Kerbal on each of Kerbin's moons.
- Put satellites around every body in the system (or at least have them waiting).

All that is left is landing Kerbals on all those other bodies. You have all the knowledge to do that already if you wish, the rest of this campaign looks at a cost-effective approach using space-stations and re-usable launch and transfer vehicles. First though, a bit of a break. The next chapter looks at small designs for science and re-usability.

Oh yes … why do I put a single solar panel on the left of the ships? Well, you could be launching at any time; morning, noon or night. In the morning the sun will be in the East – to the right – so the solar panel will be blocked during its vertical ascent until far enough through the gravity turn to get sunlight from almost directly ahead. That should be enough to keep things powered and, initially the battery/pod will be fully charged so early exposure isn't important. At noon the sun will be directly overhead so the panel should end-up getting maximum exposure after the gravity turn and in the afternoon you still get shallow-angle exposure, opposite to a morning launch. At night you're not going to get any sunlight wherever you put the panel (duh!) but once in orbit you have plenty of time to roll the vehicle before dawn. For any daytime launch the sun will be be above you and a standard gravity turn leaves the left of the ship pointing up; a simple little idea, but one that can be very important, considering how critical electricity is.

And here's a bit of totally-useless real-life trivia about mission 28: When Apollo 11 landed on the moon the winning entry in a competition to name a newly-built pub was 'The Conquered Moon'.

CHAPTER 6: PROJECT LACUNA

The Joy Of The Small

SECTION 1: PROJECT BRIEFING

Identity	Project Lacuna – Small Objects Of Desire
Background	In space-engineering less (mass) is more. What can we do under a tonne?
Objectives	Evaluate proposals for low-mass vehicles.
Payloads	Scooter, SciSat, RCS Tug, Ion Tug, Science Module.
Vehicles	N/A.
Execution	N/A.

This 'project' is rather different to the others in that there are no missions for these vehicles; they are just presented to demonstrate how effective very small craft can be. Overall, these are 'for fun' and you should read or ignore them as the whim takes you.

SECTION 2: SCOOTER

Scooter

i) Data Sheet

Identity	Scooter – Lander
Purpose	Ultra-light 1-Kerbal spacecraft
Statistics	0.7045 VAB/0.26t dry, 10 parts, cost 3,130
Design	Fuel wrapped around a core, seat and engine
Construction	QBE probe core, inline reaction wheel, LV-1 engine, external seat on top. 4x round-8 tanks offset down. OX-STAT panel and Z-100 battery
Action Groups	N/A
Performance	(Duna) TWR 1.93, 2,833m/s (vacuum)

Making a very small lander or space-scooter like this is probably not realistic but it is fun!

ii) Construction

A simple vehicle but with one little construction trick. Start with the QBE, put the IRW and engine underneath it and the seat on top. Now take a round-8 fuel tank and attach it to the *top* connection on the QBE, which the seat doesn't block. Use the offset tool to drag this tank down as far as possible – this keeps the CoM low and helps stop the scooter tipping-over when it's resting on the engine. You can now add the other three tanks on top of this one and the battery and solar panel to the sides of the QBE.

iii) Staging And Action Groups

None, unless you want to toggle the engine – there's nothing else selectable!

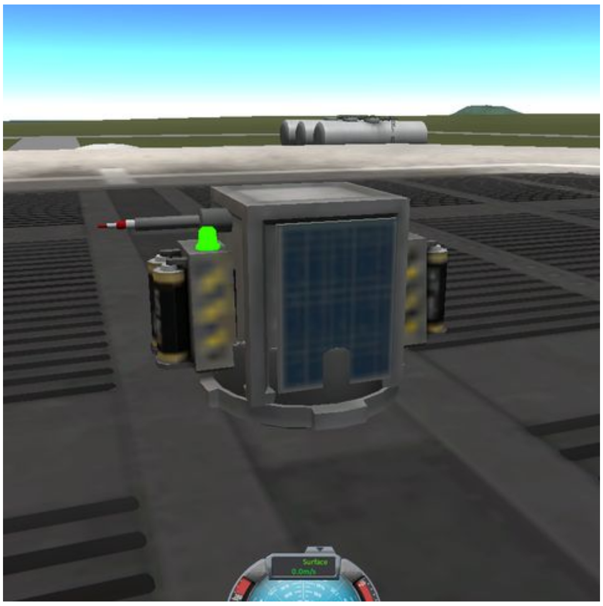
iv) Flight

Can land on and re-orbit from any body except Tylo, Laythe and Eve. Landing OR re-orbit is possible on Tylo, but not both. You can even take this to Mun on its own if you really want to. Three things to note – 1) You can't assign crew to a command seat at launch so you will need to EVA a Kerbal from another vehicle or pod, 2) if you want to recover your Kerbal you'll need to attach a pair of parachutes for balance, 3) Going to Mun on this really is unrealistic but it can do it. Have fun!

v) Notes

You have to right-click the seat from an EVA'd Kerbal and 'board' it to get into it. Watch the navball for which direction KSP thinks things are facing, you will need to 'control from here' on the QBE. Consider using two radial engines and a small docking-port on the bottom for a more versatile design.

SECTION 3: SCISAT



SciSat

i) Data Sheet

Identity	SciSat – Payload
Purpose	Tiny science probe
Statistics	0.05t, 8 parts, cost 2,120
Design	The chapter heading did mention 'small', didn't it? Quarter-tonne SCANSat satellites are just too big.
Construction	QBE, jr docking port, 2xZ-100 batteries and OX-STAT panels, 1xcommunotron 16 and 2HOT thermometer
Action Groups	N/A
Performance	No Propulsion!

This is a sandbox tutorial but I shall now nod towards career mode. In that you will be offered contracts to launch a satellite 'which has power and an antenna' and 'return science from …'. This has just enough for those types of job.

ii) Construction

About as simple as it gets – the QBE, solar panels opposite each other and the batteries on the other sides. Then place the thermometer and antenna above the batteries. If you intend to re-use this satellite by moving it to different places for science (saving money), add the docking-port on the bottom as well.

iii) Staging And Action Groups

Um-mm, 7 for the temperature maybe?

iv) Flight

No propulsion – launch and place it with other vehicles such as one of the next two, then just leave it there.

v) Notes

The QBE doesn't have reaction wheels so not only can't this move itself, it can't even change it's orientation – be careful of power, especially if transmitting.

SECTION 4: RCS TUG

RCS Tug

i) Data Sheet

Identity	RCS Tug – Drone Tender
Purpose	(Re)positioning small vehicles
Statistics	0.86t VAB/0.22t dry, 18 parts, 6,120
Design	A very light and cheap space-vehicle
Construction	QBE, inline reaction wheel, 2xZ-100 batteries and OX-STAT panels. Thrust pack: FL-R10 monopropellant tank, jr docking port and 4xRCS thruster on top and bottom.
Action Groups	N/A.
Performance	No TWR!, 3,477.2m/s (vacuum)

If the SciSat can't move, you need a tug to move it. This has no engine but relies upon RCS for thrust as well as docking. 3,477m/s deltaV is pretty useful when you're already in orbit and only need to push a small load.

ii) Construction

Pretty much what it says in the data sheet.

iii) Staging And Action Groups

Nothing to activate.

iv) Flight

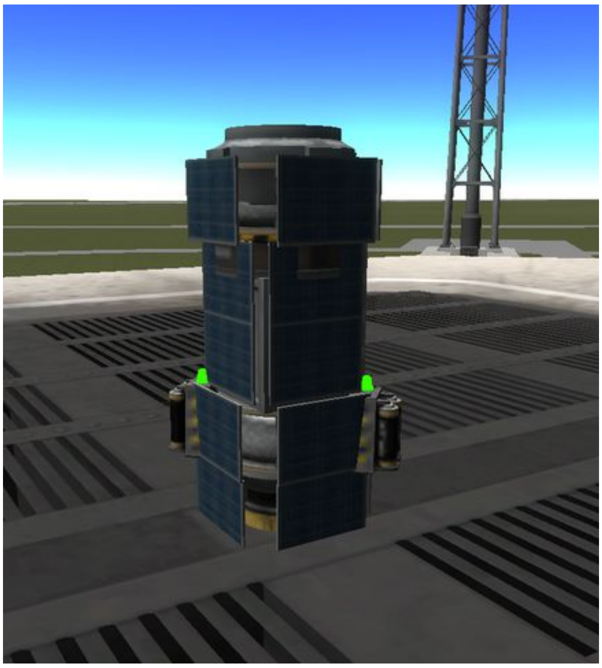
Launch and leave in orbit. When you have a satellite or other small vehicle that needs moving this can use its RCS to rendezvous and dock with it, then pull it to the new orbit, lunar SOI or wherever. Just dock a vehicle with spare monopropellant to it when it needs refuelling. Something like Orbiter Mk2 would be good for this but note the different docking-port sizes; they won't connect as is.

v) Notes

RCS doesn't offer the same fuel-efficiency as liquid-fuel, in general. On the other hand, since you probably need it for docking anyway you might as well have more of it and not carry the mass of a rocket engine. Just something to consider.

This obviously *does* have some thrust and therefore TWR but I've got no idea what it is! Low for sure, so long burn-times, especially with a payload attached.

SECTION 5: ION TUG



Ion Tug

i) Data Sheet

Identity	Ion Tug – Drone Tender
Purpose	(Re)positioning small vehicles
Statistics	0.59t/0.45t, 28 parts, cost 15,020
Design	A very efficient, high-tech space-vehicle
Construction	QBE, inline reaction wheel, 2xZ-100 batteries, PB-X150 xenon tank above and below, PN-ION engine below, jr docking port on top, 20(!) OX-STAT solar panels
Action Groups	N/A
Performance	(Kerbin) TWR 0.35, 11,172m/s (vacuum)

A high-tech alternative to the RCS Tug, this uses the most efficient engine in KSP.

ii) Construction

The QBE and IRW as before with xenon tanks above and below, the ion engine at the bottom and docking-port on top. Plaster the whole thing with as many OX-STAT solar panels as you can fit – the engine uses a LOT of electricity.

iii) Staging And Action Groups

N/A

iv) Flight

The Ion engine has an Isp of 4,000, compared to the next-best LV-N at 800, hence this has enough deltaV for a return-trip to almost anywhere. Unfortunately it uses a lot of electricity during burns and has low thrust, so those burns will be long. If you want the ultimate in efficiency you just have to live with that.

v) Notes

There's no RCS on this. You might like to add some but the very low thrust of the Ion means 'main' engine docking isn't too difficult.

SECTION 6: SCIENCE MODULE

Science Module

i) Data Sheet

Identity	Science Module – Payload
Purpose	Collecting Science
Statistics	0.47t VAB, 12 parts, cost 23,428
Design	All the instruments in a dock-able package
Construction	SC-9001 science junior, 2HOT Thermometer, Double-C Seismic Accelerometer, GRAVMAX Negative Gravioli Detector, PresMat Barometer, Mystery Goo Containment Unit, Sensor Array Computing Nose Cone, 3x cubic octagonal struts, 2x junior docking ports.
Action Groups	N/A
Performance	N/A

The SciSat is simple, but this is comprehensive. The science junior and mystery goo can only be used once each unless they are 'cleaned' at a mobile lab, which just happens to form the core of the space-station in the next chapter. Strangely enough, all the other vehicles in the rest of the tutorial can carry a science module. It's almost as if it were planned...

ii) Construction

Start with the science junior, put a docking-port on the bottom and the four small instruments down one side. The mystery goo presents a problem, in that it unbalances just about anything and carrying two would be needlessly massy. The solution here is to ~~cheat~~ use cubic octagonal struts. Place two on top of each other, on top of the science junior, with the other docking-port on top of them. This leaves room to attach the mystery goo next to them, also on top of the science junior. Now attach the third cubic octagonal strut to the top of the science junior, opposite to the mystery goo, and put the sensor array on top of that. Turn on the CoM indicator in the VAB and use the offset tool to drag the strut/sensor in and out until it balances the others, then pull it down so the sensor sits flush on the science junior. Although I haven't really stressed it using the offset and rotation tools, along with struts, is the 'art' of construction in KSP.

iii) Staging And Action Groups

N/A

iv) Flight

Carry it around with the tugs, conduct experiments, return to Kerbin for science. Use everywhere in the next chapters.

v) Notes

The remaining chapters return to the campaign to build a permanent infrastructure that only ever needs fuel and additional crew. As you move to these larger vehicles and missions remember how much can be done with very little.

CHAPTER 7: PROJECT FORTITUDE

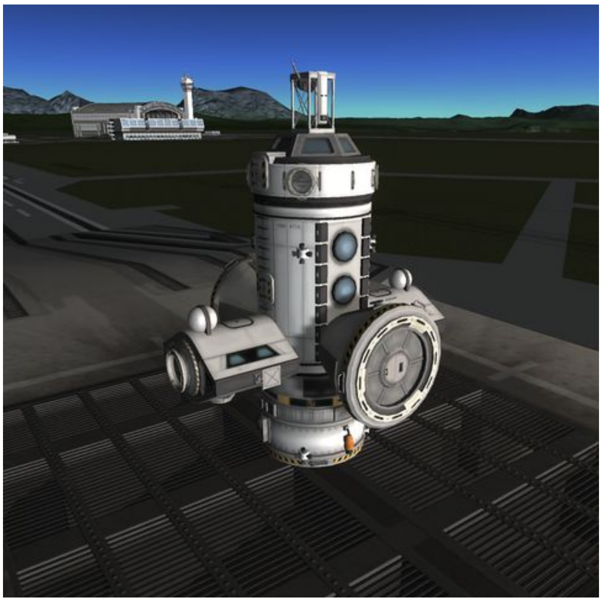
Kerbin-System Spacestations

SECTION 1: PROJECT BRIEFING

Identity	Project Fortitude – A Permanent Presence
Background	Rather than launch a complete ship for each mission the oversight committee have approved a proposal for permanent space-stations and space-based tractor/landers. This should provide a much more cost-effective way to continue our exploration of the system.
Objectives	Build a space-station orbiting Kerbin and, optionally, one or both of the moons. Use it/them to complete exploration of all three bodies.
Payloads	Station, Tractor Medium, Fuel Module.
Vehicles	SSTO 40, Crew Shuttle Mk2.
Execution	An orbital spacestation will provide a base for scientific experimentation, a refuelling point and transit accommodation for crews. Together with SSTO launch-vehicles and space-borne tractors ferrying them and any equipment between Kerbin orbit and the moons the infrastructure only consumes fuel.

The big problem with the rockets that we've been launching is that everything is lost or destroyed after each mission. Refuelling our transfer/lander vehicles in space makes them reusable, as Single Stage To Orbit (SSTO) vehicles are for launch-to-orbit. Some people never build spacestations, preferring to remain with single-mission launches and a lot adopt a 'mothership' approach (a 'station' designed to fly itself around the system). Even amongst stations there is a wide variety of intentions and designs – from minute to massive. Once again these vehicles are a big step up in size. From now on docking is also mandatory, so you'd better have been practising! You've had 3 chapters to get to grips with it.

SECTION 2: STATION



Station Core Payload

i) Data Sheet

Identity	Station – Spacestation
Purpose	Orbital science, refuelling and crew-transfer
Statistics	16.985t VAB/12.465 dry, 51 parts, cost 59,989
Design	A small station relying on separate modules for fuel.
Construction	PPD-12 cupola, mobile processing lab, advanced reaction wheel, Z-4K battery, RC-L01 probe core, X200-8 fuel tank, senior docking port. 2X 25-77 engines and PB-NUK generators. Modular girder segment with Comms DTS-M1, Communotron 16 and 88-88. 4x small docking ports on cupola. 2x cubic octagonal struts, rocomax brand adapters and senior docking ports, with 2x OX-4W solar panels. 2X cubic octagonal struts, Mk2 crew cabins and standard docking ports, with small docking port, roundified monopropellant tank and 2x OX-4W solar panels. 2 rings of 4x RCS thrusters.
Action Groups	abort:shutdown engines, 9:engines, 10:instruments
Performance	(Vacuum) TWR 0.24, 790 m/s

ii) Construction

Build the central stack of this first, including the engines and nuclear generators. In case you haven't realised yet the cubic octagonal struts are the magic components of KSP – they attach just about anywhere and create a new connection node to which you can attach just about anything else. Place two of them, with symmetry, near the bottom of the lab and build the two large docking points, then two more and the crew compartments. Once everything is in place, add the two rings of RCS thrusters equidistant from the CoM, so their thrust is balanced.

Whenever I have a station or other long-term ship I build with redundancy in mind, so they tend to have two of everything. In this case the two small ports under the crew cabins are intended for scooters (similar to last chapter) or other small personnel transports so the monopropellant tanks are kept out of the way, on top of the cabins. The four ports around the cupola are for other small ancillary vehicles such as RCS/Ion tugs, lander drones or satellites-in-transit. The large docking port at the bottom is for a tractor vehicle (next section) and the two at the sides for fuel modules (later in the chapter). The two standard ports on the crew cabins are for landers appropriate to wherever the station is placed. In the case of Kerbin, those will be SSTOs coming up from the surface, everywhere else they'll be re-usable vehicles that land then return.

In contrast to the stations I used to use this is a more stripped-back, functional, design with only the 'comms tower' on top of the station being for aesthetics (and to give something to look at from the cupola's IVA). A tractor will usually be used to move the station around so engines are not strictly necessary but it is a good idea to provide some independent means of station-keeping, as with a satellite.

iii) Staging And Action Groups

There is no staging as the whole point is for the station to remain a single piece!

Action groups are the ones from my standard assignments that haven't been used so far, because they were reserved for spacestations. Now, Custom09 (9) will toggle the station's engines and Custom10 (0) all its instruments and solar panels. The reason these are given their different groups to other vehicles is that when two or more ships are docked together they act as one. As such, it would be impossible to toggle the equipment on docked vehicles or the station independently if they shared the same groups.

iv) Flight

Space-stations more sort-of 'drift' than fly, to be honest. Use the engines and integral fuel-tank on this for orbital adjustments if the tractor is busy elsewhere, otherwise leave them shutdown. As has so often been the case; we need another launch-vehicle to get this into orbit before discussing flights properly though.

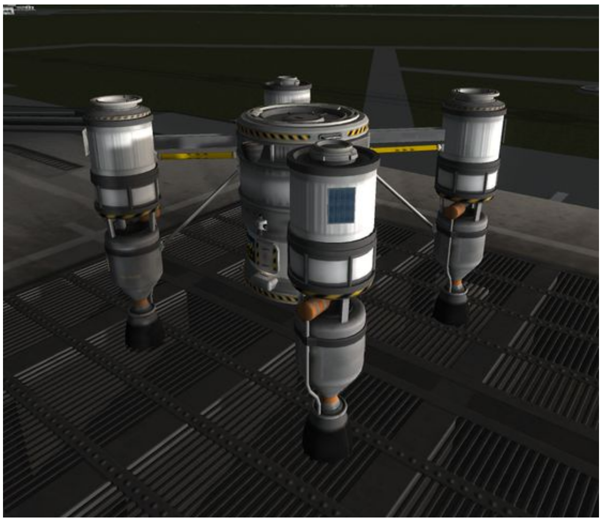
v) Notes

A chapter about a permanent space-presence built around orbital stations better start with the station itself. With reference to the 'mission briefing', however, do remember that 'a station' can look, and be built, any way you want to. This is just an example I happen to think works well and that you may choose to follow or not.

Even though stations are meant to stay put, as with satellites it's a good idea to provide propulsion for orbital-manoeuvres and corrections. Solar panels/RTGs are a must, as are docking ports all over the place but consider their placement carefully – make sure ships using the ports have enough clearance from each other, the station's deployed solar panels and instruments (or be prepared to retract them as required). It also helps avoid accidents if you use short or fixed solar panels.

Designing, building and launching separate modules then assembling them in space, by docking, gives you great flexibility. For the first time it also lets you change your mind later – if you want more accommodation just launch and dock a habitation module. Want more fuel; just stick it on there. More docking ports; you know what to do. By the same token you can de-commission modules you find you don't like, by undocking then de-orbiting or terminating them.

SECTION 3: TRACTOR MEDIUM



Tractor Medium Transfer Vehicle

i) Data Sheet

Identity	Tractor Medium – transfer vehicle
Purpose	System docking and rescue tug, lunar transfer with or without loads.
Statistics	24.9t VAB/14.74 dry, 48 parts, cost 54,894
Design	4-outrigger push/pull.
Construction	Mk2 lander can, senior docking port, advanced reaction wheel, X200-8 fuel tank, RC-L01 probe core, senior docking port. Telus-LV ladder, 2x illuminators Mk1 and Z-100 batteries. 4x outriggers with pocket I-beam, FL-T200 and 100 fuel tanks, LV-N engine, OX-STAT solar panels and fuel line from core. 2 standard and 2 small docking ports on top of the outriggers.
Action Groups	Lights:standard, abort:shutdown engines, 4:toggle ladder, 5:toggle engines, 7:instrs
Performance	(Mun) TWR 5.8, 4,034 m/s

This is the workhorse vehicle for the campaign. It can assist with docking at the station, transfer to either moon by itself or hauling a payload. While spacestations just 'sit there', tractors like this will be busy nearly all the time.

ii) Construction

The reason for the outriggers is that long vehicles, held together by docking ports, can be very wobbly and unstable. As such, it is preferably to pull, rather than push them and this means the engines can't go beneath the core – whatever the tractor is pulling will go there. Using a pocket I-beam for each outrigger ensures any payload using 2.5m parts will be kept clear of the engine exhaust. The top docking port means we can have a tractor at each end of a load if we need to – one pushing and one pulling. The standard and small ports on the outriggers provide flexibility when carrying smaller loads. Make sure the fuel lines run from the core to the outriggers – the opposite of the way they are placed for onion/asparagus boosters.

iii) Staging And Action Groups

No staging again, we're building a permanent infrastructure. Action groups are all pretty normal.

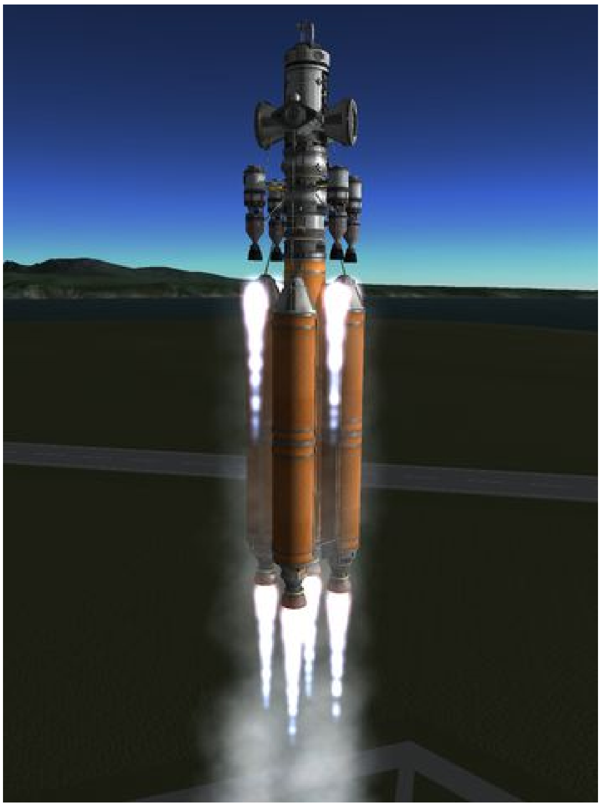
iv) Flight

Like the station itself once this is launched (next section) it will stay in space indefinitely, landing at Mun and Minmus then returning to the space-station to refuel. On its own it has enough fuel for the round-trip, including landing and re-orbit but if carrying other equipment/ships it may be necessary to attach extra fuel as well – there are plenty of docking ports of all sizes. Primarily, it is intended for a heavy/long 2.5m payload attached under the central core. Light vehicles, satellites, etc. may be attached to the outrigger ports. For very heavy loads the forward core port allows one tractor to pull and another to push; there is a lot of flexibility. First we have to get these things into orbit though...

v) Notes

It is better to pull heavy/long loads than push them. If the exhaust hits any structure behind the engines (such as the payload) it may cause damage and the thrust will be blocked. Outriggers space the engines out to keep the exhaust clear.

SECTION 4: SSTO 40



SSTO 40 + Tractor Medium + Station Core Launch

i) Data Sheet

Identity	SSTO 40 – reusable launch vehicle.
Purpose	Kerbin launch, 40 tonnes.
Statistics	(Ex payload) 386.3t VAB/66.3 dry, 42 parts, cost 163,348
Design	Core + 4, Single Stage To Orbit
Construction	RC-L01 probe core, advanced reaction wheel, large docking port, 2x jumbo-64 fuel tanks. 2x stacks with 2 jumbo tanks, rocomax brand adapter, drogue parachute and OX-STAT solar panel. 2x stacks with 2 jumbo tanks, adapter, Mk16-XL parachute; one with illuminator Mk1, the other with a Z-100 battery. Fuel-lines from core to - and mainsail engine under - each side-stack.
Action Groups	Brakes: parachutes, abort:shutdown engines, 3:toggle engines
Performance	(Kerbin) TWR 1.58, 6,231 m/s

We're trying not to throw anything away now, so this is a Single Stage To Orbit design. That's not efficient for a single launch but in career-mode, or for role-play purposes, it means all you have to pay for is the fuel (if you can land back at KSC).

ii) Construction

Start with the central stack then the side-stacks with symmetry. Apart from making sure the four side-stacks are connected by fuel-lines from the core there's nothing difficult about this build – it's intended to be low part-count, robust, reliable and easy to build and fly.

iii) Staging And Action Groups

Action groups are, as always, abort to shutdown and Custom03 to toggle the engines. Brakes seems a suitable group to use for the parachutes. Staging, from bottom should be set to engines, drogue parachutes and main parachutes. Note, however, that 'staging' only activates things here, nothing is jettisoned so it can all be recovered and reused.

iv) Flight

Use SSTO 40 to launch a tractor medium together with a station stacked on top, setting the tractor's engines to ignite straight from launch, at the same time as the launch vehicle's. Although they don't provide much thrust and this is using the payload's fuel the LV-Ns are very efficient so, overall, whatever contribution they make saves a little fuel. Once in orbit you can transfer fuel back from the launch vehicle to ensure the payload tractor is fully-stocked.

NOTE: SSTO 40 connects to the payload with a docking-port, not the decoupler/separator used in the earlier launch vehicles. This is so it can, if required, be used to land a payload coming back from space (e.g.; an empty fuel module). Unlike decouplers, however, docking-ports enable fuel crossfeed. When you go to launch you must (right-click and) disable this on the launch-pad or the launch-vehicle engines will suck all the fuel out of your upper stages. Not only can this leave you with a useless payload, if you don't spot it, but it can even upset the balance of the rocket so much during launch that it will be unflyable. You have been warned.

MISSION 34: Home port

Tractor Medium + Station Core

Position a spacestation and tractor in a 250km equatorial orbit around Kerbin. There is no escape system for the station or tractor during launch so send them up unmanned. Use SSTO 40 to put them into a low orbit, then undock and use the tractor to place the station properly. Note the docking-port connection between the tractor and station, with reference to above.

MISSION 35: Recycling

SSTO 40 Re-entry (with Deadly Re-Entry mod)

You've parachuted command-pods down to Kerbin, done powered-landings on Mun and Minmus and landed jets on the runway. Now for a (parachute-assisted) powered-landing on Kerbin.   Make sure SSTO 40 is in a low Kerbin orbit and proceed as for landing the Orbiter/Long Tom/Fat Sally recovery stages. After the de-orbit burn you should have 300 or 400m/s deltaV remaining. Deploy the drogue parachutes high, 7km if you wish, and their drag will slow your descent sufficiently to open the main chutes around 1-2km without them being torn off. Together they'll bring your descent down to about -20m/s but that's still too fast for the engines to absorb the impact … *just* before you touch-down, probably under 200-300m, you need to apply SAS to keep upright and some throttle so the engines reduce your descent to -5m/s or so. Too much and you'll start ascending again and KSP will cut the parachutes, too little and you'll crash. Start too early and you'll possibly burn all the fuel before landing and you'll crash, start too late and you'll crash. This is known as a 'suicide burn', because of the consequences of getting it wrong. Unless you've been using this technique on Mun/Minmus a lot of practice will probably be required.

SSTO 40 Touchdown (in the car-park)

Actually, it's not that bad as long as you don't waste too much fuel on your de-orbit burn. You're only reducing speed from ~-20m/s to -5m/s so you can start early and use low throttle. Just keep a close eye on your VSI and adjust throttle as required. (Or use MJ, like I do).

v) Notes

A nice, simple and robust, reusable launch vehicle for quite a heavy load. (40t is only 'quite' heavy in KSP, but at least you've left 'small' behind). Design SSTOs like this for 4,900m/s+ deltaV at launch, so they have fuel left for landing. Parachutes aren't essential but without them you'll need more fuel for the suicide burn (and more practice).

The big question about orbital spacestations is where to put them. Low, 75km, orbits make them easy to reach for vehicles that are launching but leaves no room beneath them for a phasing orbit, if one is required for rendezvous. A higher, 600km, orbit provides an efficient departure-point for interplanetary trips but is harder to reach for launching vehicles and leaves, if anything, too much work to be done by those that are de-orbiting. My preferred 'traffic control' zones use the following orbital heights (which, as always, you should feel free to ignore):

75km – launch/de-orbit vehicles and low phasing orbit
150km – low rendezvous/parking orbit
250km – space-station orbit
350km – high rendezvous/phasing orbit
600km – interplanetary parking orbit

SECTION 5: CREW SHUTTLE Mk2

Crew Shuttle Mk2 In SPH

i) Data Sheet

Identity	Crew Shuttle Mk2 – spaceplane.
Purpose	Surface-Station crew transfers.
Statistics	8.223t VAB/5.055 dry, 53 parts, cost 44,962
Design	A flat beetle with high performance
Construction	Mk2 crew cabin with RC-001S and shielded docking-port in front. Nose-wheel under cabin, advanced canards on the sides. Mk2 liquid fuel fuselage and liquid fuel + oxidiser fuselage (both short), advanced inline stabiliser and turbojet behind cabin with delta wings. Twin Rocomax 48-7S engines beside turbojet, RAM intakes above and below wings and rear fuselage, small gear bays on wingtips; all attached with cubic octagonal struts. Tailfin, control surfaces, Z-100 battery, communotron 16 and solar panels. Stratus-V roundified monopropellant tank under stabiliser and thrusters around CoM.
Action Groups	Gear, lights, brakes:standard, abort:shutdown engines, deploy parachutes, 1:jets, 2:intakes, 3:rockets, 4:toggle port, 5:cabin lights, 7:instrs
Performance	(Kerbin) Takeoff/Landing 40m/s, Ceiling ~69km, max speed >2,200m/s

This spaceplane uses “intake-spamming” and moderate part-clipping to achieve high-performance but some people might consider it cheating.

ii) Construction

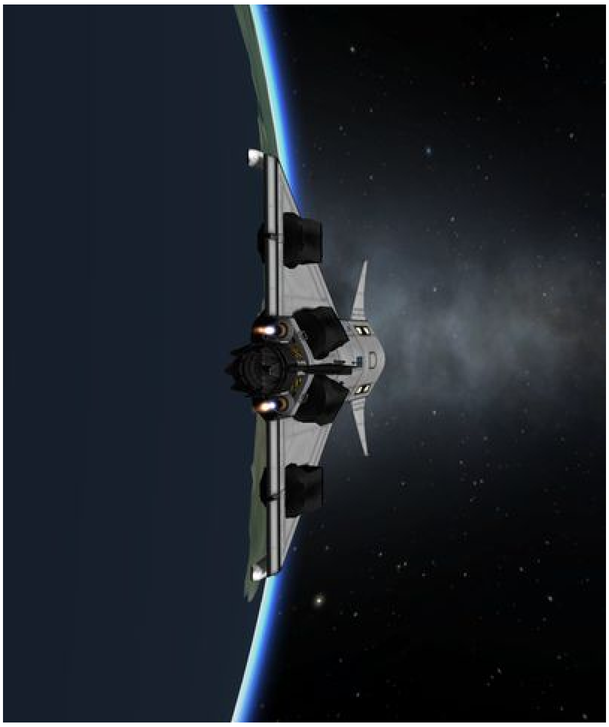
The Mk2 crew cabin is the lightest way to carry multiple crew to the space-station. Fit a short liquid fuel (only) fuselage behind this and then a short liquid fuel + oxidiser fuselage. With this arrangement fuel is first taken from the forward tank, making the CoM move back slightly. Once you ignite the rockets, however, the oxidiser has to come from the rear tank so the CoM moves forward again. If you burn all the fuel the CoM comes back to only just in front of the CoL at worst but never moves very far. There is no Mk2-shaped decoupler but the mk16 parachutes are enough to save the crew cabin, if not the rest of the vehicle. Monopropellant is provided by a roundified tank tucked under the stabiliser (use WASD so it doesn't hit the ground on take-off and landing) and thrusters around the CoM. Otherwise, wings, tailfin and control-surfaces as normal for any plane.

There are eight ram air-intakes on this design; four around the fuselage near the tailfin and four on the wings (two each side). This gives a huge amount of air for the jet engine, enabling it to be run right to the edge of space (69km) and leaving only 30-50m/s deltaV from the rockets to circularise a 75-80km orbit. This is abusing KSP physics somewhat and it is a little bit 'cheaty' to use so many intakes, especially as you have to fake attachment-points for them. For this, first position a cubic octagonal strut – they'll affix anywhere – then attach a ram intake to its free node. You can now use WASDQE to position and align the intake as you wish.

iii) Staging And Action Groups

The set for spaceplanes. Gear, light, brakes and abort as you'd expect. 1 to toggle the jets, 2 the intakes and 3 the rockets. 4 is just used to open/close the docking port and 7 to toggle the antenna/sensor. I'm not really sure if it's worth mentioning 5 – the lights option was there so I thought I'd go for it.

iv) Flight



Crew Shuttle Mk2 Circularising Orbit

Standard start for spaceplanes: fine controls, SAS enabled, activate jets and throttle to max. Review the instructions for flying the Orbiter Mk2 (chapter 4) to orbit – spaceplane ascent is in three phases and, with the separate jet and rockets of this design you'll have to be more careful of the middle stage. Rotate to 50-degrees at 60m/s and climb-out to 10km for the first phase. Reduce pitch to 30-degrees and start to build horizontal speed while climbing to 20km, then reduce pitch further; to 10-degrees. Up to 30km, and especially above 25km, try to adjust your climb-rate so that your horizontal speed is at least 1,000m/s plus 100m/s for every km above 20km – so 1,100m/s at 21km, 1,200m/s at 22km, etc. Unlike the rapier the jet is entirely dependent on intake air, so you must go fast enough to feed it. Using this approach, or something close to it, you should be able to exceed 2km/s at or around 30km. Above approximately 33km there will be insufficient air for the jet and it will 'flame-out', but don't switch to rockets yet. Instead reduce throttle a little until the jet re-ignites. Although providing less thrust there is so little drag at this altitude that it will still be able to accelerate you, or at least assist your speed, as long as you keep throttling-back as you get higher. Pitch flat (0-degrees) or even down so your apoapsis climbs to 75km+ while the rest of the thrust increases your periapsis. You should be able to get a horizontal speed over 2,100m/s with an apoapsis at orbital altitude and periapsis already above 30km – my best being 58km – by running just the jet all the way to the edge of the atmosphere (69km) where it will finally give up. Close the throttle (X), deactivate the jet (1), close the intakes (2) and switch to rockets (3) while cruising to apoapsis, where you can circularise as normal, probably requiring less than 50m/s deltaV from the tiny 48-7S engines.

MISSION 36: Home From Home

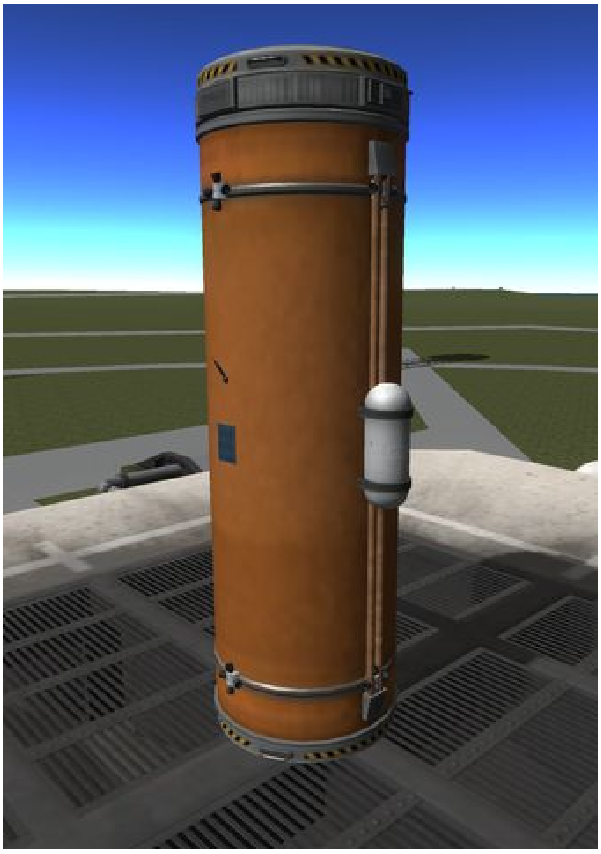
Use the Crew Shuttle Mk2 to ferry the crew to the space-station. At Kerbin, I usually have a pilot station commander, engineer and two scientists for the lab. If you like to role-play 'reality' you might want to make a note to yourself to replace the station crew every month (or whatever tour of duty you think is suitable).

v) Notes

Intake-spamming and part-clipping can provide very high-performance vehicles and improve appearance by hiding parts but a lot of people would consider some uses of it (eg; clipping an engine inside another or inside a fuel tank) as cheating.

Yes – the jet/rockets combination is more complex to fly than a rocket or rapier, but it is much more efficient. My flights to orbit with the Crew Shuttle Mk2 usually only need 50-100 units of liquid fuel and 5-10 of oxidiser; most of the flight burning just liquid fuel and the oxidiser only being used for circularisation. This and throttling-back the jet to keep it burning as long as possible is the key to practical spaceplane operations, although the rapier is a good place to start. Read spaceplane tutorials before using multiple jets/rapiers – 'asymmetric' flame-out or mode-switching can make you crash.

SECTION 6: FUEL MODULE



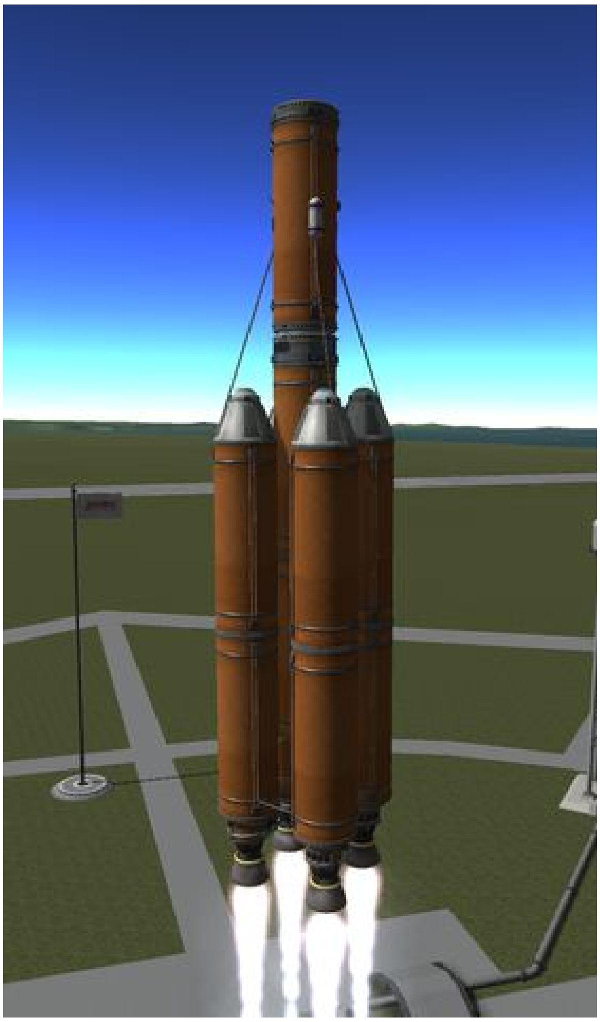
Fuel Module Payload

i) Data Sheet

Identity	Fuel module – payload
Purpose	Dockable, reusable, fuel pod for space-stations and tractors.
Statistics	38.4t VAB/5.2 dry, 18 parts, cost 23,940.
Design	Rather than 'just' a can of fuel this is a complete, if limited, drone vehicle.
Construction	RC-L01 RGU, docking port sr, jumbo-64 fuel tank, sr. docking port below. Z100 battery, communotron 16, 2x OX-STAT solar panels and Stratus-V cylindrical RCS tanks. 8 x RCS thrusters.
Action Groups	7:antenna
Performance	N/A but 81m/s RCS

Now that we have a station in orbit, a shuttle to take crews to the station and back and a tractor to transfer them onwards to the moons, the only thing missing is more fuel. This module is intended to dock with the space-station, enabling it to refuel the tractor and any other vehicles that visit. The large docking ports at either end maintain the station's flexibility while the solar-panels and battery mean it can also be left in space as an independent vehicle, if you wish – presumably waiting for something to come and use its fuel.

ii) Construction



SSTO 40 + Fuel Module Launch

A simple stack, look at the pictures. Make sure the RCS thrusters are balanced around the CoM.

iii) Staging And Action Groups

No staging, it's reusable.

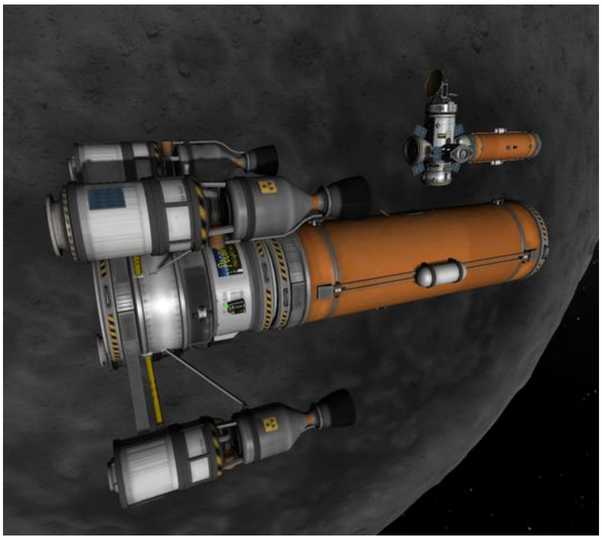
iv) Flight

Without an engine this won't be doing much flying (although it can dock, as noted above). Launch with SSTO 40, use Tractor Medium to move it around. Recover empties with SSTO 40 or add parachutes for self-landing. A typical cycle would be; launch to orbit with SSTO 40 when the station exhausts one it already has, Tractor Medium brings empty tank to rendezvous with SSTO 40, exchanges fuel then returns full tank to station, SSTO 40 lands with now-empty tank.

v) Notes

At, roughly, 40t this is the heaviest single thing I usually launch, anything bigger can be assembled in space, by docking.

MISSION 37: Kerbin Complete



Tractor Medium Delivering Fuel Module To Mun Station

Launch two fuel modules into orbit. Rendezvous and dock with them using the tractor medium transfer vehicle. Use the tractor to carry them back to the station and dock them to the two clear central docking-ports – as in the illustrations. Visit any remaining anomalies or 'sites of interest' on Kerbin using a spaceplane or orbiter.

MISSION 38: Minmus Mapped

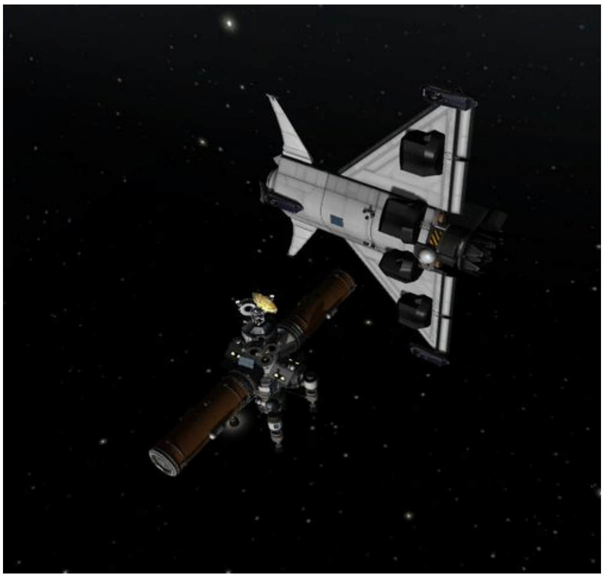
We have, all along, been using the SCANSat satellites to map the moons. The intention then being to visit and identify any anomalies with manned missions. Check your Minmus map – found any yet, or other sites you'd like to land at?

If there are only one or two sites you want to visit on Minmus it isn't worth placing a space-station there. Just use the tractor to transfer to, land on and return from Minmus. After each trip it can refuel at the space-station and is immediately ready for another mission – profit! You might think the pilot needs a rest/replacement though so you can send up new crew with the shuttle which, being a spaceplane only needs refuelling between missions too (automatically, on the ground) – profit!

MISSION 39: Mun Maximised

Now check the SCANSat map for Mun – there are probably quite a few places you want to visit there. Instead of sending the tractor all the way to Mun, landing and coming all the way back just to visit one location at a time, it's time for another station. Placing a second space-station around Mun (50km orbit is fine) means the tractor can land, re-orbit, refuel and land again as required. You will probably want to use a second tractor as well – to bring another fuel module across from LKO if the Mun station starts to run low. This is the complete infrastructure make-up – crew and fuel launch from Kerbin surface to Kerbin station, tractors shuttle between Kerbin station and the station nearest the objective, e.g.; Mun, refuelling as required. At the destination station the only remaining task is to land and re-orbit/dock.

As to how to get the station to Mun in the first place – there are two main approaches. Dock station and fuel modules in LKO then use the tractor to tow the whole thing to Mun in one go. This works, but it's a bit of a load for the tractor so you'll have long burn-times. Alternatively, tow one or both fuel-modules first, come back and take the station to them, docking it all together in LMuO. From now on, HOW you perform missions is up to you to work out!



Crew Shuttle Mk2 Approaching Kerbin Station

The final chapter details specific landers so the tractors don't have to do *all* the work.
Nearly Finished!

CHAPTER 8: PROJECT ENDURANCE

Landers, landers, (almost) everywhere

SECTION 1: PROJECT BRIEFING

Identity	Project Endurance – Anywhere
Background	With the home-system infrastructure in place it remains to extend it to the other planets and moons.
Objectives	Place space-stations and dedicated landers around all celestial bodies of interest.
Payloads	Landers Drone, Light, Medium, Tylo and Laythe
Vehicles	(Launch from Kerbin with appropriate launch vehicles from earlier chapters)
Execution	Equip space-stations with landers, move or assemble space-stations – with their fuel, landers and tractors – around all required destinations. Use these to complete exploration of the system.

“Landers” are vehicles specifically designed to shuttle between the surface and orbit of a particular body. Crew Shuttle Mk2 and SSTO 40 are the 'landers' for Kerbin, those presented here cover everywhere else except Eve. These are all intended to carry a science module, refuel at space-stations and be moved around in space, if necessary, by a tractor or tug. Suitable designs are, conveniently, provided by the previous two chapters, in case you skipped them.

We are now designing vehicles that are ONLY required to land from a low-orbit space-station (or transfer vehicle) and re-orbit and dock with it later. So:

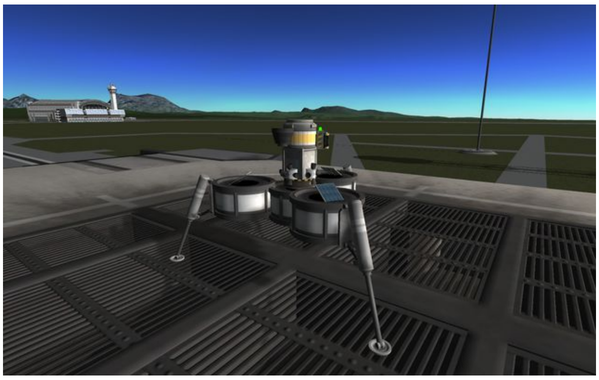
"How hard is it just to land (from local orbit, m/s)?" table

Gilly	30
Pol	130
Minmus	180
Bop	220
Ike	390
Dres	430
Mun	580
Eeloo	620
Vall	860
Moho	870
Duna	1,300
Tylo	2,270
Laythe	3,200
Eve	12,000

(Jool & Kerbol N/A)

(Double these figures to include later re-orbit). In this chapter Gilly to Dres are considered 'low' deltaV, Mun to Duna 'medium', Tylo and Laythe are treated individually and Eve is … ignored (see notes at the end of the chapter). The landers are intended to dock directly to a station but if you are using them with a tractor or tug that can do the docking you can save some mass and deltaV by removing the lander's monopropellant and thrusters.

SECTION 2: LANDER DRONE



Lander Drone

i) Data Sheet

Identity	Lander Drone – Lander
Purpose	Unmanned medium deltaV planetary landings with science module
Statistics	2.97t VAB/0.65t dry, 25 parts, cost 6,610
Design	Symmetry-3 SSTO
Construction	QBE, inline reaction wheel, FL-T100, 48-7S. 3x FL-T100, OX-STAT solar panel, landing leg and fuel line. FL-R10 monopropellant tank, small docking port, Z-100 battery, illuminator Mk1, communotron 16, 4x RCS thrusters.
Action Groups	Abort, gear, lights: standard, 6: toggle engine, 7: toggle antenna
Performance	(Kerbin) TWR 1.03, 3,846 m/s

'Medium' deltaV planetary landings means suitable for any body up to and including Duna, as explained above.

ii) Construction

Reaction wheel, one fuel tank and the 48-7S engine under the QBE, RCS tank and docking port on top of and battery, light, antenna and thrusters around it. Radially attach the symmetry-3 fuel tanks then add the solar panels. Connect these tanks to the engine with the fuel lines. Nice and easy.

iii) Staging And Action Groups

Nothing special; just the engine and antenna toggles.

iv) Flight

For all these landers flight is assumed to start docked to a space-station. The usual procedure would be to undock and use RCS to dock with a science module connected to the same station. Undock the science module from the station and use the lander to take it to the surface. Conduct all experiments, re-orbit and re-dock the science module to the station for lander refuelling, report-transfer and equipment 'cleaning', without which the science junior and mystery goo can't be reused. Either repeat the descent/ascent or undock the lander alone and park it back on its own station-port.

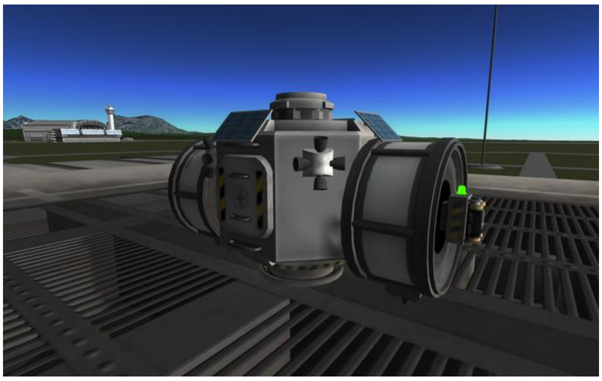
MISSION 40: Duna Done

Duna is the easiest place to reach beyond Kerbin's moons and now you have a lander that can explore it. You should already have visited it with Cartographer Light and investigated it from space with your SCANSat satellites. Now it's time to build a space-station there, equip it with lander drones and visit the surface of another planet. Use a Tractor Medium to carry Fuel Modules there first and come back empty. Use a second tractor to take the station itself and dock everything in space. A third trip may be necessary (but shouldn't be) to take Lander Drones – I recommend a pair of them – and any extra fuel, however you prefer.

v) Notes

Performance figures are given without science module payload. You may, of course, substitute your own or use the lander alone.

SECTION 3: LANDER LIGHT



Lander Light

i) Data Sheet

Identity	Lander Light – Lander
Purpose	1-man low deltaV planetary landings with science module
Statistics	1.955t VAB/0.895t dry, 22 parts, cost 7,084
Design	Symmetry-2 SSTO
Construction	Mk1 lander can, OKTO 2, standard and small docking ports, 4x OX-STAT solar panels and RCS thrusters. 4x cubic octagonal struts, FL-T100 tanks, Z-100 batteries, LV-1 engine.
Action Groups	Abort: standard, 6: toggle engine,
Performance	(Kerbin) TWR 0.42, 2,040m/s deltaV

You can just use the Lander Medium in the next section for any body up to and including Duna but this is a lighter, cheaper option for those that require a lower deltaV.

ii) Construction

The only thing to note about the construction of this is that I have used cubic octagonal struts to place the fuel-tanks 'sideways' on the lander-can and then to connect the engines on their lower edge. Placing them radially as normal is simpler but wider – choose how you like things, there are always several ways to do the same thing.

iii) Staging And Action Groups

Yes, there are some.

iv) Flight

A lander should have a low CoM and wide base to stop it falling over. This one doesn't but on the low-gravity bodies it is intended for you're more likely to have trouble staying down than pointing the right way. SAS and RCS provide a lot of force in these places. Otherwise – just the same as the Lander Drone, what else can I say?

MISSION 41: Gilly Grabbed

After Duna the target of choice for deltaV is Eve. Specifically, Gilly is your landing target – do NOT land on Eve if you want to get anything back! Gilly is tiny and, as you can see from the table above, has a very low requirement for landing. The comment above about staying down is particularly true of Gilly.

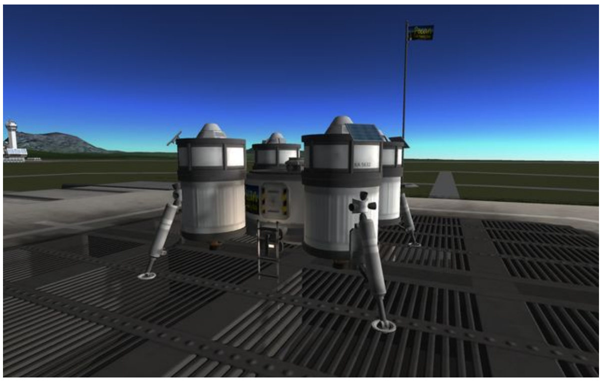
MISSION 42: Dres Discovered

Ahhh, Dres, enjoy! In many ways it's the perfect secluded holiday destination. In other ways it's the most boring body in KSP. Dres just never gets enough love.

v) Notes

There's no ladder on this design so your Kerbal might have to jump to get back in.

SECTION 4: LANDER MEDIUM



Lander Medium

i) Data Sheet

Identity	Lander Medium – Lander
Purpose	2-man medium deltaV planetary landings with science module
Statistics	10.52t VAB/4.36t dry, 35 parts, cost 14,558
Design	Symmetry-4 SSTO
Construction	Mk2 lander can, OKTO 2, standard and small docking ports, telus-LV ladder, 2x z-100 batteries. 4x FL-T200 tanks, lander legs, OX-STAT solar panels, RCS thrusters, 48-7S engines and (Duna only) Mk16 parachutes.
Action Groups	Abort, gear: standard, brakes: deploy parachutes, 6: toggle engine, 8: toggle ladder
Performance	(Kerbin) TWR 1.16, 2,903m/s deltaV

If you only want one lander for Duna or easier bodies then choose this. It is capable enough that without the parachutes it can 'hop' between a couple of biomes on low-gravity places before re-orbiting and refuelling.

ii) Construction

Okto 2, docking ports, batteries and ladder on the lander can, everything else on the 4 radially-attached fuel tanks.

iii) Staging And Action Groups

Don't forget the ladder.

iv) Flight

No special considerations.

MISSION 43: The Whole System

Place stations, tractors, drones and landers around all the other planets. Add additional stations and their associated vehicles around any moons (except Tylo and Laythe) you consider deserve them.

v) Notes

The parachutes are only useful for Duna because that's the only place with an atmosphere. Remove them for less mass and more deltaV when used elsewhere. If using on particularly low-gravity bodies you might want to thrust-limit the engines as they have a lot more thrust than is required.

SECTION 5: LANDER TYLO

Lander Tylo

i) Data Sheet

Identity	Lander Tylo – Lander
Purpose	Manned Tylo landings with science module
Statistics	37.58t VAB/9.42t dry, 25 parts, cost 23,464
Design	Symmetry-2 SSTO
Construction	Mk2 lander can, Skipper engine, advanced reaction wheel, X200-8, small docking port, Z-100 battery, telus-LV ladder. 2xside-stacks each; X200-8 and X200-16 tanks, OX-STAT solar panel, fuel line, 2x RCS thrusters and lander legs.
Action Groups	Abort, gear: standard, 6: toggle engine, 8: toggle ladder
Performance	(Kerbin) TWR 1.76, 4,966m/s deltaV

Tylo's a lot tougher than Duna.
The landing and re-orbit round trip requirement is about the same as for a Kerbin launch but there's no atmosphere to slow you down and you can't use parachutes. The benefit of having no drag during launch is more than lost in the effort and TWR it takes to land safely in the first place.

ii) Construction

The usual simple stack with two radially-attached side tanks. Remember the fuel lines.

iii) Staging And Action Groups

The usual.

iv) Flight

Despite the high deltaV requirement landing and re-orbit are normal for a vacuum body.

v) Notes

Yes, you can use this on easier places but there's no good reason for doing so.

SECTION 6: LANDER LAYTHE

Lander Laythe

i) Data Sheet

Identity	Lander Laythe – Spaceplane
Purpose	Manned Laythe landings and flight with (integrated) science module
Statistics	5.593t SPH/3.705 Dry, 62 parts, cost 62,389
Design	Lightweight with compact-wings and comprehensive science package
Construction	Mk1 Inline cockpit, RGU, shielded docking port, telus-LV ladder, small gear bay. Science Module (without ports), Mk1 liquid Fuel fuselage, FL-T200, turbojet, tailfin and elevon 4. 2x wings; each 4x wing strakes, 2x elevon 4, 1x cubic octagonal strut and 48-7S engine, cubic octagonal strut and small gear bay. Z-100 battery, 2x OX-STAT solar panels, 4x RCS thrusters, 8x cubic octagonal struts and RAM intakes.
Action Groups	Abort, gear, lights, brakes: standard, 1: jet, 2: intakes, 3: rockets, 4: docking port, 5: ladder
Performance	(Kerbin) Takeoff/Landing 60m/s, Ceiling ~69km, max speed >2,200m/s

If 1km/s deltaV more than Duna makes Tylo tough you'd think another 1km/s would make Laythe *really* hard but not once you look at its atmosphere. Not only does it have one, so parachutes are useful and drag will slow your descent, but it's the only place apart from Kerbin with an oxygen atmosphere. That means jets work there and so spaceplanes are an ideal way to get around.

ii) Construction

The cockpit, ladder, etc. are simple enough. Behind that put a standard science module (assuming you saved it as a sub-assembly) but remove the docking-ports. The fuselage will then fit on the cubic octagonal struts or directly to the science junior. The intakes, rockets and landing gear are attached using cubic octagonal struts, as seen before.

The particular feature of this design for construction considerations though is its wings. These are constructed of multiple small 'wing strakes' instead of using the usual single-piece delta or swept wings. Even more unusually, while the wing strake against the fuselage is placed as normal the second, attached to the first, is rotate backwards to make a squarer structure. The two outer strakes are then added facing forwards as expected. In KSP wing segments produce their rated lift at 0 or 180 degrees to the airflow but no lift if placed sideways. Remember this if you're rotating parts on your own designs.

iii) Staging And Action Groups

Woo – a lot compared to the other landers. The whole set for spaceplanes, in fact.

iv) Flight

This flies just like any other spaceplane and will work quite happily on Kerbin, if you wish. The important thing to note for Laythe, however, is that the atmosphere is not as thick so you should aim for a 60km orbit and flatten-out to build speed correspondingly lower.

MISSION 44: Special Circumstances

You won't be surprised that this mission is to land the specialised Tylo and Laythe landers on their respective moons, refuelling at a dedicated station or the one for the whole Jool system, as you decide.

v) Notes

The main advantages of using this instead of one of the other spaceplanes is its low mass and complete set of scientific instruments. Using a standard science module instead would make balancing the plane very complicated because it would have to account for the differences in CoM with and without the payload.

SECTION 7: GAME OVER

i) Eve

You're on your own with Eve, it's a special case for which, as warned, I'm not providing a lander. It's easy to land on Eve because it has a thick atmosphere; just make sure you have plenty of parachutes and strong landing-gear. *Launching* from Eve is a whole different story though. Look at the deltaV requirement – it's nearly 4 times Laythe or 2.5 times Kerbin. You will also need to maintain an Eve TWR of 2 or more for nearly all of the ascent, so you need a lot of thrust. In stock KSP it is not possible to make an Eve lander in a single-stage and it isn't easy even with staging. It is possible though – keep your payload as light as possible (a single external command seat is favourite), consider asparagus staging (see LV-8-A) and concentrate on efficiency, not aesthetics.

There are a lot of forum threads and challenges regarding Eve landers – good luck.

ii) Optimisation

From Chapter 4 onwards the vehicles here are all pretty good – for a given value of 'good'. If nothing else they will have shown you that missions everywhere are possible. A major part of the ongoing fun of KSP however is optimising your own designs for the criteria you choose. As discussed in the section on LV-6-S these can be any of mass, cost, part-count, aesthetics, or anything else you can think of. So – how light can you make a return Mun vehicle? How quickly can you get to Minmus and back? Just how good-looking can you make an Eve lander?

For a lot of people it takes a year or two before they have built everything they want to in KSP – I hope you find it as rewarding too.

iii) Rovers and bases

The big omission from this campaign is in the building of rovers and bases. With the increase in biomes on all bodies rovers are more useful than in earlier versions of KSP but it is still generally better/easier/quicker to have a lander visit each one, refuelling as necessary. On those occasions when I do use rovers they are either very tiny probes or landers fitted with wheels instead of landing-legs. Bases are simply vehicles that are parked on the surface so there's nothing special in their design. They can become complicated if you want to build them out of several sections, however, because it can be difficult to move them together and align docking ports. As always, refer to the forums for advice and guidance.

iv) Farewell

Thank you for reading this campaign tutorial. I hope it has been helpful and has inspired you to create your own vehicles. Your own designs will always be a better source of pride and achievement. Have fun!

Appendix 1: Index Of Ships

Appendix 2: Summary Of Mission DeltaV

(m/s requirement)

Body	Transfer & Orbit From LKO	Seq	Transfer, Orbit & Land From LKO	Seq	Land Only From Local Orbit	Seq
Bop	5,920	14	6,140	11	220	4
Dres	3,860	7	4,290	7	430	6
Duna *	1,700	4	3,000	5	1,300	11
Eeloo	4,790	12	5,410	9	620	8
Eve *	2,880	5	14,880	14	12,000	14
Gilly	2,950	6	2,980	4	30	1
Ike	1,550	3	1,940	3	390	5
Jool *	5,170	13	---	---	---	---
Kerbol	33,680	16	---	---	---	---
Laythe *	4,360	11	7,560	13	3,200	13
Minmus	1,430	2	1,610	1	180	3
Moho	6,640	15	7,510	12	870	10
Mun	1,170	1	1,750	2	580	7
Pol	4,040	10	4,170	6	130	2
Tylo	3,860	8	6,130	10	2,270	12
Vall	3,890	9	4,750	8	860	9

* Marked bodies allow aerobraking.