Using Space Games like SimpleRockets, Spaceflight Simulator, and Kerbal Space Program to Teach Kids Orbital Mechanics

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ABSTRACT

Kids love space exploration, but they do not necessarily know how rockets and spacecraft actually work. Kids can use space-themed games based on physics to learn more about how metal cylinders full of propellant move and interact in space while still having fun. We talk about our example videos with a focus on kid space fans to help them get started. We use games that are currently available in stable releases, starting first with basic concept 2D games like SimpleRockets, and then to Spaceflight Simulator, which is also 2D. From there, we give examples of progressing to 3D motion and bigger parts in SimpleRockets 2, now known as Juno:New Origins, Kerbal Space Program, and the new release of Kerbal Space Program 2. We will go over how to teach kids about concepts like delta-V and specific impulse. Our goal is to help kids and teachers progress from simple concepts like suborbital trajectories and getting to orbit, to the more advanced concepts like rocket staging, orbital transfers, rendezvous, landings, and finally, the resource conservation and efficiency needed to make it on interplanetary trips.

Our goal is to share these videos with kids old enough to use keyboard controllers or iPhones easily (like grades 3 and up) and share them to the community so that kids can have an easier time on their own, and so that teachers do not have to do as much work making lesson plans and becoming familiar with several types of games at different levels of difficulty. We also include summary material on how teachers can get kids access to free or educational versions of these games. We also include tips and rules-of-thumb, such as using solid rocket boosters for getting off of a surface and out of an atmosphere and getting lots of thrust, when to do gravity turns, using different kinds of engines for atmospheric pressures versus in the vacuum of space, the importance of orbital inclination, understanding which shapes are aerodynamic and which will burn up fast, and why gravity assists will save you thousands of meters per second of delta-V. We hope that by having this series of videos that get harder as you go through them, kids will be able to see their improvement as they go. We hope more kids use these tools to become interested in aerospace and develop a good sense for how rockets and spacecraft work so they can grow up to become professional aerospace engineers and help our country and society explore space.

INTRODUCTION

Our goal is to develop a series of tutorial videos so that Kids can watch them to learn about orbital mechanics. While there are a number of videos about space flight games online, they are not set up in a logical way that goes from easy to hard, and are sometimes very long. Sometimes they also focus only on one level of difficulty or one program, which makes it harder for a new learner to understand and make progress.

In this work, we will cover topics like which games are useful to get to learn about space flight, which platforms can be used, and how we develop video content that starts by describing basic parts and terms and simple tasks like suborbital space flight in '2D' before progressing to multiple rocket stages, orbital space flight and landing, lunar orbit insertion, lunar landing, understanding reaction control thrusters,

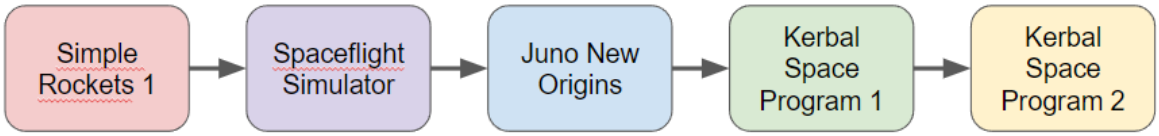

Figure 1: Progression of the not-necessarily-related space exploration games that are used in the tutorials, from left to right by level of difficulty (easiest on the left to most challenging on the right). Also see Tables 1 and 2 for more detail.

lunar landing and return, interplanetary orbit insertion, interplanetary landing and return. We also then consider increasing complexity with heat effects and drag, as well as moving up to space flight in '3D' and more complex goals and objectives.

This paper is organized by starting with an Introduction (this section), followed by an Approach which will contain more about the programs and platforms used and a table of the video topics. Then we will describe some Analysis of video topics, along with a Summary, and Plan for Future Work. The tutorial videos are currently being developed and distributed on the Rocket Ahoy YouTube channel.

APPROACH

In this section we describe in some detail the games that are used in the tutorials. Table 1 and Table 2 provide a high level summary of the topics covered in the videos, as described in the Discussion section.

Steam

Steam is a software distribution platform that allows users to find, purchase, and install games, including those used in this educational effort so that kids can learn about space flight and orbital mechanics. Steam can be installed on PCs running Windows, Mac, and Linux operating systems. It is also possible to download and install the games used in this work individually, but Steam is a convenient solution. Guardian support is needed to double-check for appropriate content and to provide purchasing information for kids.

SimpleRockets

SimpleRockets is the first game we use for teaching about space flight and orbital mechanics. SimpleRockets keeps things intuitive and uncomplicated. For example, it is only in '2D' instead of full '3D' control. Full '3D' control has roll, pitch, and yaw (also called Euler angles). SimpleRockets has a user interface that is easy to explain and use, as a 'control circle' that orients the rocket as user increases or throttles the engine thrust.

SimpleRockets also has no thermal effects and has limited choices for vehicle parts and configurations. The limited choices are helpful at this stage, as they do not overwhelm the user with options. SimpleRockets has a few sizes of liquid engine ('Sloshy'), and one type each of solid (Solid Rocket Booster, SRB) and ion engine to choose from. There are solar panels and batteries that can be used for the electric-powered ion engines. SimpleRockets does not have a lot of technical specifications on engine performance listed for its parts, and keeps things straightforward and clean.

SimpleRockets also has a easy to use reaction control system (RCS) with thrusters that are allow for finer control of the vehicle orientation (also called spacecraft attitude). The capsule in SimpleRockets is manned. There are very simple rendezvous and docking capabilities as well as some funny docking exercises that are intentionally not well matched.

In this work, we use SimpleRockets to get started becoming familiar with suborbital flight, making it to orbit, making it to lunar orbit insertion, landing on the 'Smoon' and returning to 'Smearth', making it to 'Smars' orbit insertion, landing on 'Smars' and returning to 'Smearth', as described in Table 1. In the SimpleRockets tutorials we also go over maneuver rules of thumb like to change your periapsis you need to thrust at your apoapsis, and to change your apoapsis you need to thrust at your periapsis.

Spaceflight Simulator

Spaceflight Simulator is another relatively straightforward game that does not yet involve '3D' space

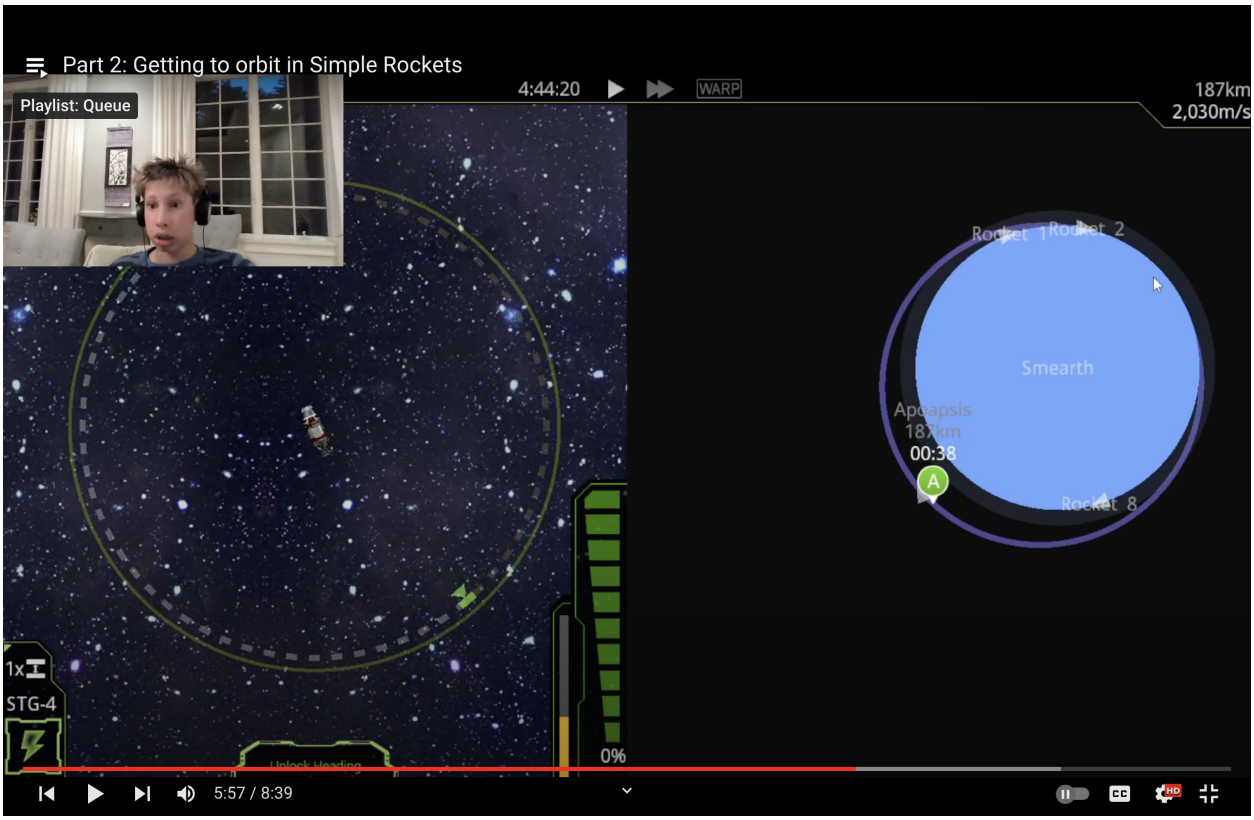

Figure 2: Example of @RocketAhoy demonstration video using SimpleRockets to get to Smearth orbit. The left hand image is of the vehicle control circle and engine thrust/throttle, and the right hand image is of the map with the orbit parameters.

Table 1: SimpleRockets Tutorial Video Topics

Number	Description
1	Putting a rocket together and suborbital flight
2	Orbital flights and rocket stages
3	Sphere of influence and lunar orbit insertion
4	Lunar landing and return to Earth
5	Using Reaction Control Systems for landings
6	Interplanetary orbit transfers and insertion
7	Interplanetary landing and return (like Mars)

flight. Spaceflight Simulator is generally '2D' like SimpleRockets, but has more complicated effects like thermal (heating) by the planet atmospheres and significantly more options for parts. The engines have performance parameters like mass, thrust, and specific impulse. There are also liquid chemical, solid rocket, and ion engine options in Spaceflight Simulator, as well as solar panels and batteries for the ion engines.

Spaceflight Simulator also has RCS control thruster options. There are also probes in Spaceflight Simulator, which are unmanned capsules that can be flown. Like SimpleRockets, we will show suborbital flight, making it to orbit, making it to lunar orbit insertion, landing on the Moon and returning to Earth, making it to Mars orbit insertion, landing on Mars and returning to Earth, and introduce the concept of gravity assists. Manned vehicles are not yet available in Spaceflight Simulator. Spaceflight Simulator lets you pick environments that are Normal, Hard, and Realistic where things like the scales, specific impulse, and masses vary.

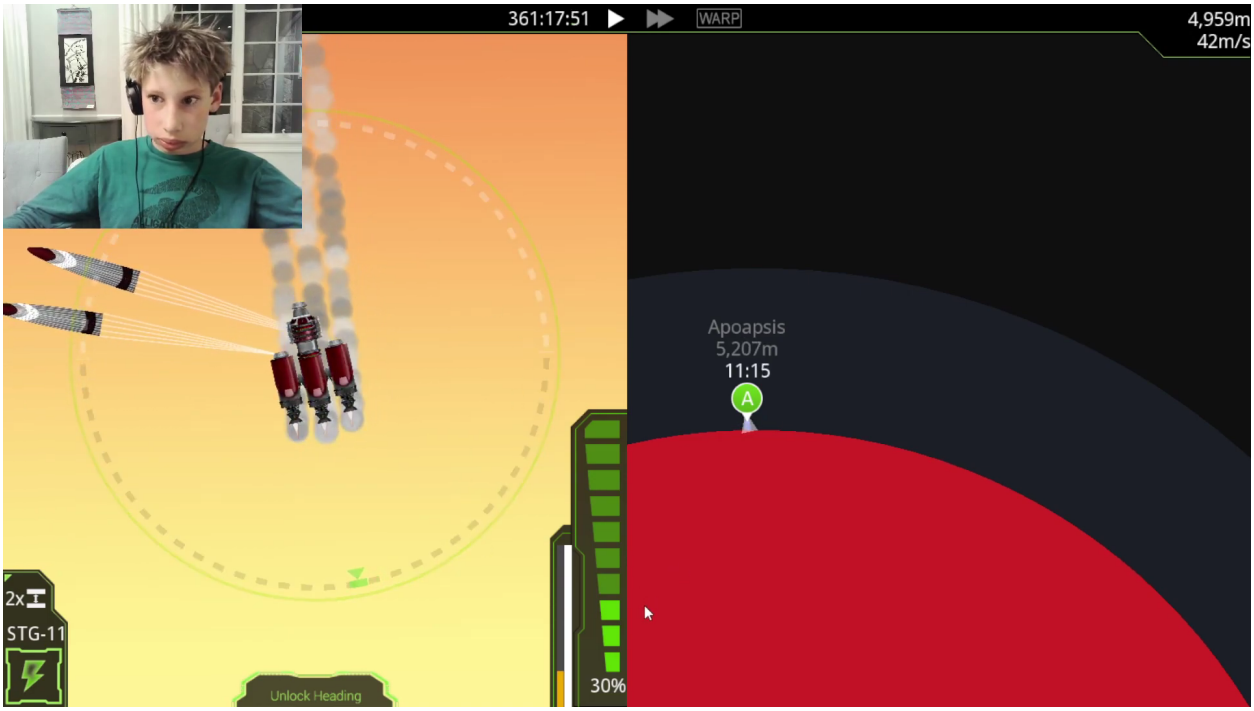

Figure 3: Example of @RocketAhoy demonstration video using SimpleRockets to get to a Smars landing. The left hand side shows the vehicle and engine controls with parachutes, the right hand side shows touchdown on the surface.

SimpleRockets 2 (Juno: New Origins)

Juno: New Origins (JNO) is an upgrade to SimpleRockets that involves '3D' space flight. Unlike in SimpleRockets and Spaceflight Simulator, in JNO the vehicle controller is represented by two orthogonal circles, kind of like a gyro, one for pitch (blue circle), and one for heading (orange circle). This type of navigational tool is also called a Flight Director Attitude Indicator (FDAI). JNO also has manned vehicles, and rendezvous and docking are also possible. The play modes in JNO are Sandbox mode, where you do not make money or tech tree points, and Career mode, where these points are the main objective.

Kerbal Space Program 1

Kerbal Space Program (KSP) is also a full-featured '3D' space flight program that uses a 'navball' for control. KSP also includes thermal effects, has a large parts library, detailed technical specifications, and manned vehicles (by Kerbals). In KSP, the key controls are pitch (the W/S keys) roll (Q/E) and yaw (A/D). We use KSP for more detailed build, small body exploration, docking and rendezvous tutorials. KSP also has different user objectives, like Career Mode and Science Mode. In KSP Science Mode the objective is to earn science points to unlock the tech tree. There is no money but you have to spend science points to get the parts. In KSP Career Mode, you earn science points and money, and you use both advance on tech trees.

Kerbal Space Program 2

KSP2 is in early release at the time of writing, and intended to support interstellar space exploration as well as multiplayer action.

DISCUSSION OF TUTORIAL VIDEO TOPICS

The sequence of video tutorials in development follows the progression in Figure 1. The structure of the videos will be fairly similar for each of the programs, just focusing on the updates and differences as the programs become more complex.

0.1 SimpleRockets

Figure 2 shows an example of the orbiting SimpleRockets tutorial. The '2D' navigation circle and engine thrust control are shown along with the sim-

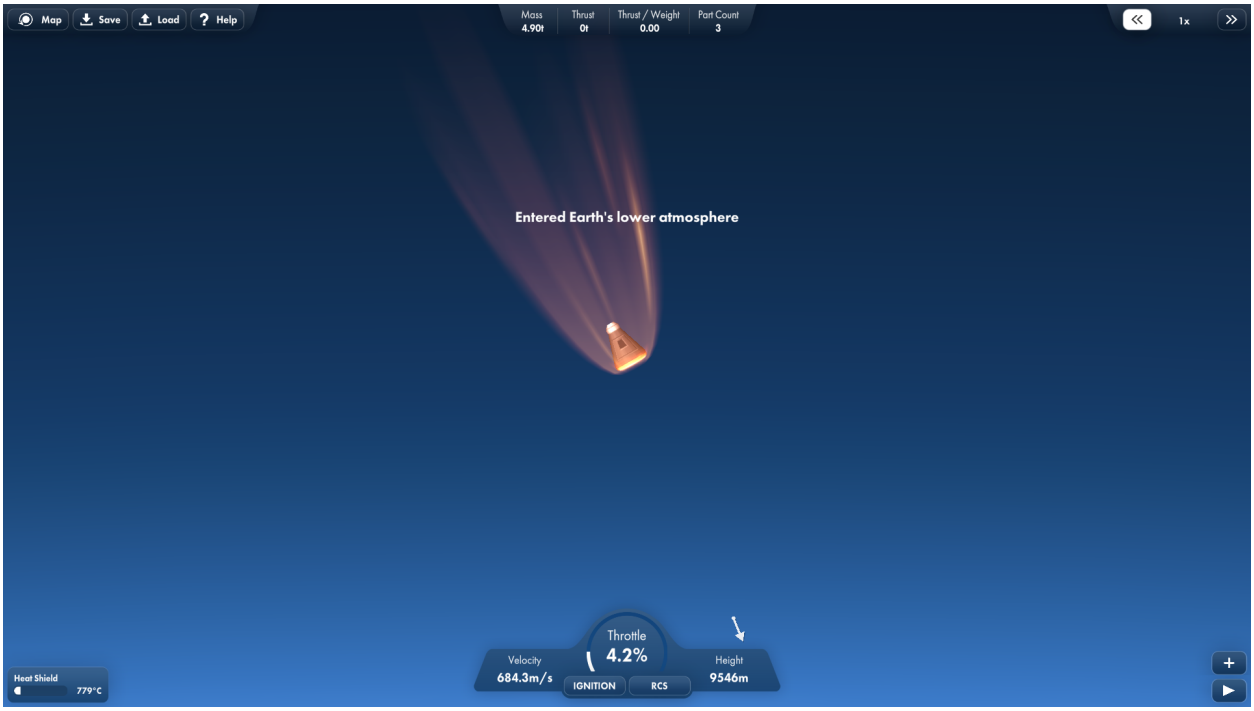

Figure 4: Example of the thermal effects that need to be managed in Spaceflight Simulator, but that do not play a role in SimpleRockets.

Table 2: Advanced Tutorial Video Topics, in addition to those in Table 1.

Number	Description
1	Rocket assembly with advanced parts and thermal effects (Spaceflight Simulator)
2	Introduction to Gravity assists (Spaceflight Simulator)
3	Putting a rocket together with adjustable advanced parts (Juno New Origins)
4	Flying using '3D' controls (Juno New Origins)
5	Using gravity assists for interplanetary exploration (Juno New Origins)
6	Playing for Career Mode (Juno New Origins)
7	Putting a rocket together with an expansive part library (Kerbal Space Program)
8	Small body deep space interplanetary exploration with Minmus (Kerbal Space Program)
9	Docking and rendezvous (Kerbal Space Program)
10	Playing for different objectives like Science Mode and Career Mode (Kerbal Space Program)
11	Rocket assembly with large and customizable part library (Kerbal Space Program 2)
12	Interstellar exploration (Kerbal Space Program 2)

ple orbit parameter map. SimpleRockets is a good place to get comfortable with becoming accurate in direction and thrust timing. Gravity turns are also discussed, it is important to do on takeoff from any orbit in order to efficiently get into orbit, but is different from a gravity assist, which is later shown as a useful way to conserve fuel. SimpleRockets has gravity assist possibilities but it is more effective to learn about gravity assist in stronger gravity like Spaceflight Simulator or other advanced programs. It is also important to learn to keep landings slow and to pay attention carefully to altitude and orientation.

With fewer parts in SimpleRockets, it is a good place to learn about how to put together a rocket, and to learn about what happens when you forget things like landing legs, reaction control thrusters, detachers, and parachutes. All of these elements get far more complicated in the advanced games. It is also not as difficult to achieve interplanetary transfers in SimpleRockets, which is a mixed blessing, because

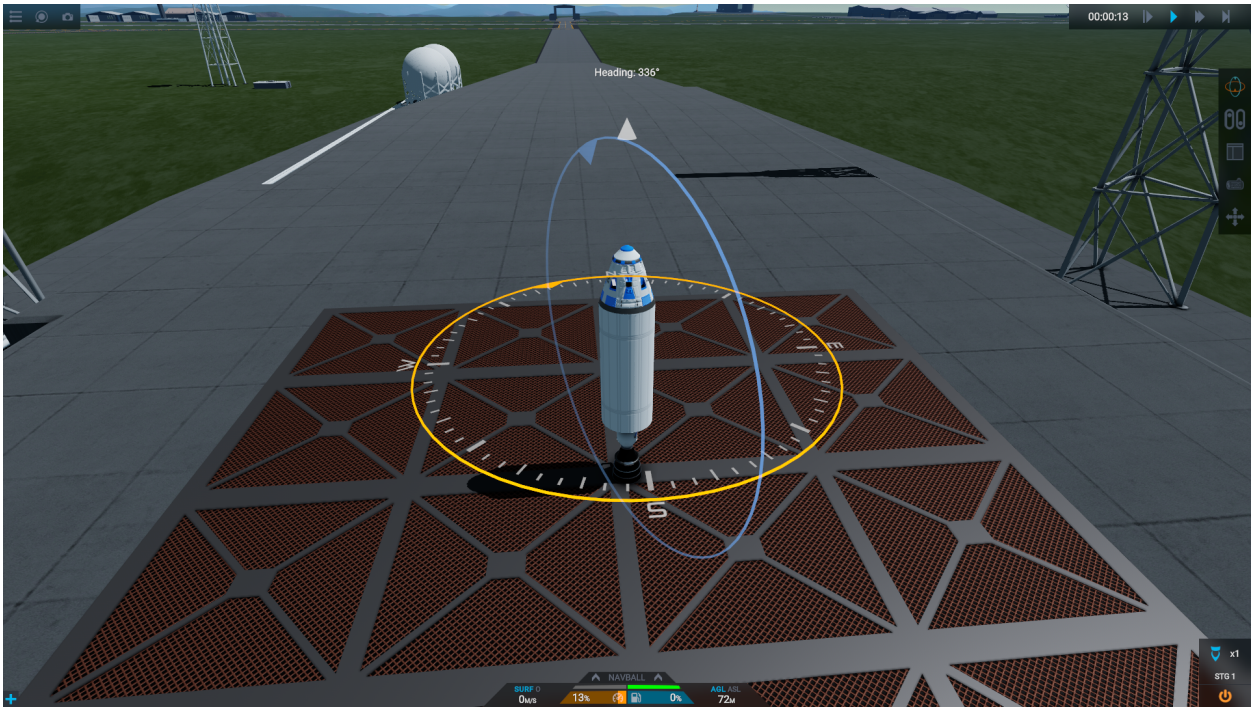

Figure 5: Juno New Origins (formerly SimpleRockets 2) showing takeoff from 'Droo'. The two orthogonal 'control circles' are shown, blue is pitch and orange is heading.

although you learn some of the basics like how to succeed with an encounter, you are still not fully prepared for interplanetary transfers in the '3D' games, but will be in a better place to start.

Figure 3 shows and example of a Smars landing in SimpleRockets. On the left hand side you can see the parachutes being deployed as the space vehicle with rockets lands on Smars. The parachutes help to slow the rocket down, so there is some atmospheric drag force in SimpleRockets, but there is no thermal heating. More than one parachute is helpful to slow down effectively on Smars because the atmosphere is thinner than on Smearth. On the right hand side of Figure 3 the landing orbit parameters are shown, with the apoapsis approaching Smars. A thin Smars atmosphere is also visible.

0.2 Spaceflight Simulator

Figure 4 shows an example of a capsule re-entering Earth atmosphere after a suborbital flight. Spaceflight simulator includes thermal effects on the spacecraft from interacting with the planet atmosphere. In this case, the capsule is heating up as it re-enters. It is possible to burn up the capsule if the heat shield is not oriented properly along the velocity direction. The temperature of the capsule is shown in Figure 4 at the bottom left of the screen. Temperatures are reported for parts that are being heated, in this case, the heat shield. Atmospheric drag also is a more important aspect to manage in Spaceflight Simulator.

Spaceflight Simulator is a good game to spend time learning about gravity assists because the modeling is more effective around massive planets. Using Earth for gravity assists on the way to Mars is a useful first example before trying other interplanetary gravity assists. The hardest part about gravity assists is making sure that you have an encounter that pulls your orbit around the body as close as possible with dealing with the body's atmosphere or crashing so that the vehicle can gain more velocity upon exiting the encounter and thus saves fuel.

0.3 Juno New Origins

Figure 5 shows the '3D' user control circles in JNO, blue is pitch and orange is heading. JNO complexity is higher than that of Spaceflight Simulator because managing orientation and timing in '3D' is significant harder because there are many more possibilities. It is useful to repeat the suborbital, orbital, lunar, and interplanetary lessons in a '3D' environment, where entry, descent, and landing becomes much

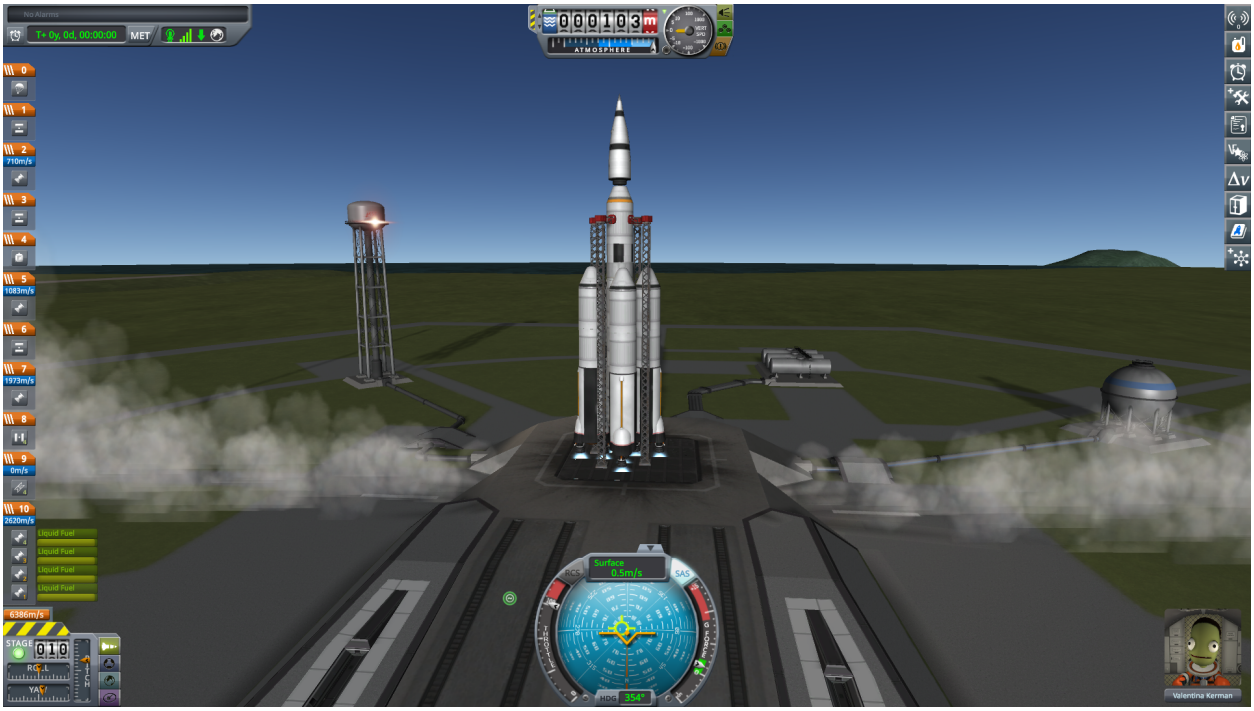

Figure 6: Kerbal Space Program rocket configured to launch to the 'Mun' and to 'Minmus'. The 'navball' is shown.

more complicated.

0.4 Kerbal Space Program

Kerbal Space Program is one of the most detailed space flight simulation programs but the learning curve can be a bit steep, which is why it is useful to have the '2D' games like SimpleRockets and Spaceflight Simulator to start with. Figure 6 shows a rocket constructed by the author, referred to as 'Jupiter 12' that is designed for a launch from Kerbin to the Mun or Minmus. On the screen you can see the navball in the bottom center, which summarizes the orientation and velocity of the vehicle. The orange dip line is where you are facing, the yellow crosshairs is the prograde, and the g-force loading on your Kerbal passengers is also shown. Up at the top center are parameters including altitude, velocity, and proximity to space. Stages are shown on the left, and utilities are shown on the right.

Figure 7 shows a fun example of a manned mission with Kerbal Valentina on an extravehicular activity (EVA) also known as a space walk, while on a rocket the author named 'GRFS' before ultimately heading to Duna (the Mars analog). The navball is orange in Figure 7 because the vehicle is facing toward the south of Kerbin. When the navball is blue, like in Figure 6, the vehicle is facing toward the north of Kerbin or the planet it is orbiting.

0.5 Kerbal Space Program 2

Figure 8 shows a rocket built in KSP2, which is a new release of KSP that is intended to eventually support interstellar travel and multi-player activity. In Figure 8, the navball is in the lower left, with velocity information. Both KSP and KSP2 have control support capability like Stability Assist Service. KSP2 is still in development and does not yet include effects like thermal, although it does currently have atmospheric drag.

SUMMARY

This paper describes an effort to provide kids with resources to self-teach about space flight and orbital mechanics using already-available games. It is helpful to start with '2D' games like SimpleRockets, and then advance through skill development, as described in Tables 1 and 2 to more complex and fun '3D' games like JNO and KSP.

Figure 7: Kerbal Space Program manned spaceflight participant 'Valentina' on an extravehicular activity (EVA).

Future Work

In the future, the author would like to continue to expand upon the tutorial videos. It is unclear how long the content will be current before platform software and game versions change significantly. These games have similarities to professional-grade aerospace engineering tools like STK and research tools like poliastro or Orekit. It would be great to have workshops for kids where we can progress through the games, maybe even competitively, and earn prizes. Then we could start to develop tutorials to help understand the algorithms and functions behind the game capabilities and grow the ability of our society to explore our solar system and beyond.

ACKNOWLEDGMENTS

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Figure 8: Kerbal Space Program 2 showing an orbital test flight.