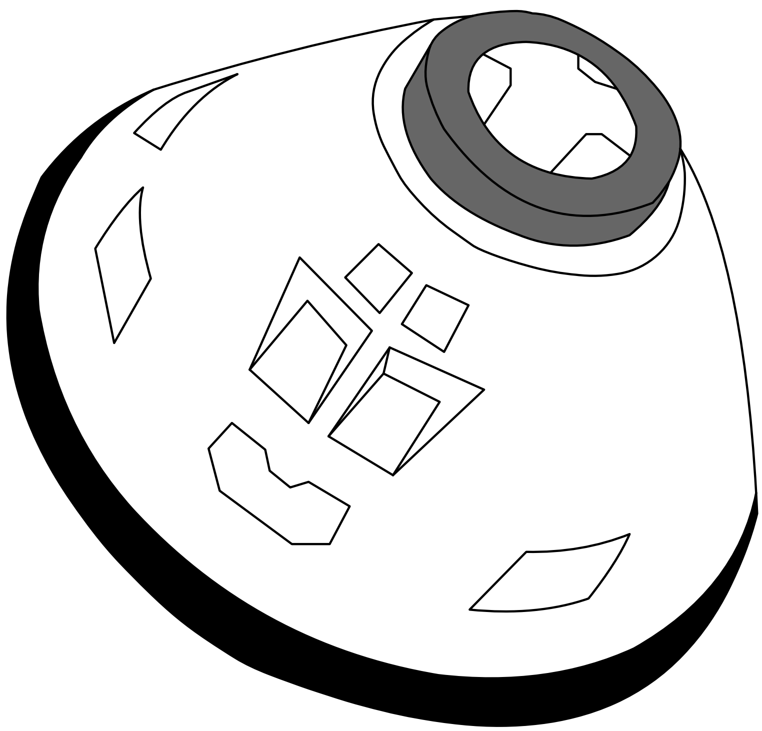
eXperimental Space and Aeronautics Group

RV-55x Ares-1/Orion



Black Phoenix

January 11, 2012

Contents

Chapter 1

Quick Reference

1.1 General Information

Click on very top of the MFD. (on the first line of text, for example) It will pop up the same MFD screen, this clone can be dragged around and will stay on screen.

One can safely push all the buttons MFD has, this will never cause any control issues. This is not the same with other buttons - they might do things that are can hurt the spacecraft.

Click around the buttons on left and right of the MFD before the ascent to change target orbit parameters.

The rocket will initially be put into orbit with a high apogee and a perigee that might be below the planet's surface. This is intentional: the second stage booster that was dropped will burn up in atmosphere shortly.

Some keys can be bound to RCS commands (sim/rcs/xp, ...), but it's also possible to simply push `TRANS INPUT` button to enable the translational input. This will change the joystick from rotational input to translational input.

The big indicator above the `SRB IGNT` button is the orbital counter. It shows how many circles around the Earth have been made.

Remember: burn at apogee changes perigee, burn at perigee changes apogee.

1.2 Glossary

Units of measurement The spacecraft uses metric system of units everywhere. 1 meter is approximately 3 feet, 1 kilometer is approximately 0.5 miles. Water boils at 100 degrees C, and freezes at 0 degrees C.

Orbit A stable trajectory of a very fast moving spacecraft which does not interesect with Earth.

Orbital elements A set of variables which define the orbit, for example apogee and perigee.

Orbital plane An orbit is a trajectory on a single plane. This is called the orbital plane.

Apogee Point at which spacecraft is furthest away from Earth.

Perigee Point at which spacecraft is closest to Earth.

Inclination Rotation of the orbital plane from the Earth equator.

Semimajor axis Defines ellipse that represents the orbit. Is equal to an average between apogee and perigee.

Hohmann transfer An easy and moderately efficient transfer between two orbits. Requires two engine burns.

Semimajor transfer Transfer which only changes either apogee or perigee. Requires just one orbit burn. Two of these make up a Hohmanns transfer.

Heat flux Flow of heat over a unit of area, per unit of time. A measure of how much thermal energy goes through a certain surface.

Velocity vector Mathematical vector, a representation of the direction spacecraft flies towards.

Prograde Oriented along the velocity vector - facing the direction of motion.

Retrograde Oriented against the velocity vector - facing away from the direction of motion.

RCS Reaction control system - a set of small rocket engines used for orienting spacecraft around in space.

OMS Orbital manuevering system - one or more rocket engines used for changing the current orbit.

DAP Digital autopilot - a special computer program which controls spacecraft motion.

MFD Multi-functional display - a computer display which provides various flight information, depending on the current mode (function) selected.

Powered Explicit Guidance A mathematical algorithm which computes trajectory the spacecraft must fly based on its current state, and the state it must have at the end of guidance.

Delta-V Change of the spacecrafts velocity. May be used in context of total delta-V that a spacecraft has - the maximum change of velocity that can be done using its engines.

Burn An orbital manuever which consists of firing an engine into a specific direction to change the spacecraft's velocity.

Re-entry A special manuever which consists of lowering spacecraft into dense atmosphere, and using the friction to reduce its velocity. Generates a massive amount of heat, which is absorbed or reflected by the spacecrafts heat shield.

1.3 Flight Mode Reference

The on-board software is divided into sections called flight modes. Each flight mode is a distinct portion of the software, and will perform only a certain subset of features. The computer will automatically transfer between these flight modes.

During the on-orbit operations it is possible to change the current mode either by using the event programer, or by using buttons under the MFD.

Flight mode	Description
00	Idle
10	Stage 1 ascent (pre-programmed guidance)
11	Stage 1 ascent (active guidance)
20	Stage 2 ascent (early ascent)
21	Escape tower separation
22	Payload fairing separation
23	Stage 2 ascent (late ascent)
30	Stage 3 / On-orbit idle
31	Stage 3 / Kill-Rot autopilot
32	Stage 3 / Att-Pro autopilot
33	Stage 3 / Att-Ret autopilot
34	Stage 3 / Orbital normal + autopilot
35	Stage 3 / Orbital normal - autopilot
40	CM / On-orbit idle
41	CM / Kill-Rot autopilot
42	CM / Att-Pro autopilot
43	CM / Att-Ret autopilot
44	Stage 3 / Orbital normal + autopilot
45	Stage 3 / Orbital normal - autopilot
50	Ballistic reentry stabilization
51	Active atmospheric braking
52	Free flight
53	Parachute descent
54	Braking jets
55	On ground
60	Controlled reentry

1.4 Cockpit Buttons Reference

1.4.1 Keyboard

The keyboard is used for programming the on-board event controller.

1.4.2 `TRANS INPUT`

Toggles between translational and rotational control via joystick. The pitch axis will control movement on X axis (forward/backward). The roll axis will control movement on the Y axis (left/right). The yaw axis will control movement on the Z axis (up down).

This mode is used for more precise manuevers when two spacecraft are close together.

1.4.3 `LAND JETS`

Arms the landing jets. They are the rockets which soften touchdown after the capsule landing on Earth.

Landing jets are operated by the flight software, and will fire automatically if armed during landing.

1.4.4 `LAZY DAP`

This button controls fuel consumption and precision of the digital autopilot control. When this button is in pressed state, the autopilot will conserve fuel by making less adjustments to attitude.

1.4.5 `PV EXTEND`

Extends solar panels. Not available in this release.

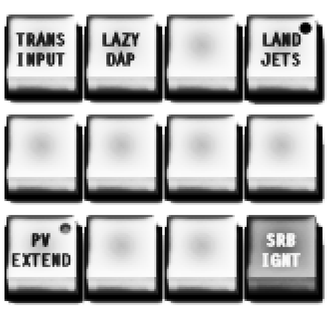


Figure 1.1: Buttons on the left panel

1.4.6 `RCS ON`

Enables or disables the reaction control system thrusters. These are the thrusters used for orienting ship, changing its attitude.

1.4.7 `KILL ROT`

Changes into flight mode 31. The spacecraft will fire reaction control system jets to stop any residue rotation it might have.

1.4.8 `ATT PRO`

Changes into flight mode 32. The spacecraft will fire reaction control system jets to orient itself along velocity vector.

1.4.9 `ATT RET`

Changes into flight mode 32. The spacecraft will fire reaction control system jets to orient itself against velocity vector.

1.4.10 `ORB ENGN`

Arms the service module engine. This will provide control of the engine (throttle will start it up).

1.4.11 `DROP ARM`

Arms separation of the service module. It is only required for manual separation using the `DROP STAGE` button.

1.4.12 `DROP STAGE`

If `DROP ARM` is pressed, this button will deattach service module from the capsule.

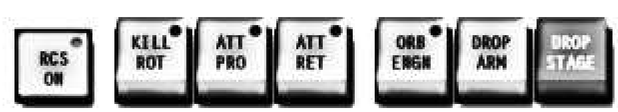
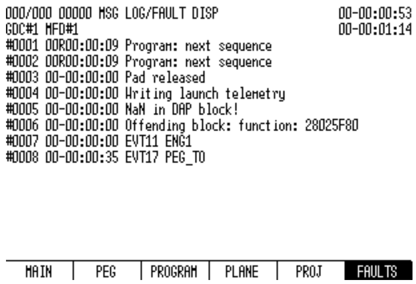


Figure 1.2: Buttons under the MFD

1.5 MFD Screens Reference

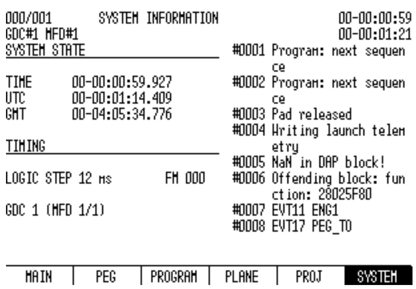
1.5.1 FAULT (Message Log/Fault Display)

This screen will display all key events, error messages, and notifications that occur during spacecraft operation.



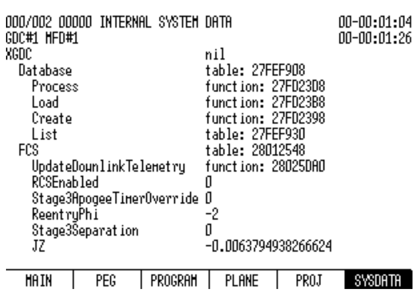
1.5.2 SYSTEM (System Information)

This MFD screen displays some operating system information.



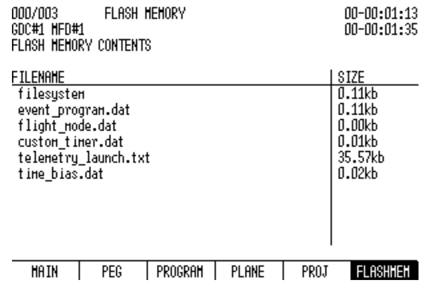
1.5.3 SYSDATA (Internal System Data)

The Internal System Data screen is used for low-level operating system troubleshooting.



1.5.4 FLASHMEM (Flash Memory)

Flash memory/filesystem state is displayed on this screen. It lists files and their sizes.



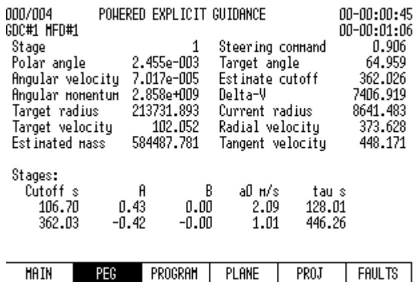
1.5.5 PEG (Powered Explicit Guidance)

This screen is used for monitoring state of the active guidance during ascent. It displays the following variables:

- `Stage`: currently active rocket stage
- `Polar angle`: angular distance travelled by the rocket, in radians
- `Angular velocity`: angular velocity of the rocket (in Earth-centric inertial coordinates)
- `Angular momentum`: total angular momentum of the rocket in the inertial coordinates
- `Target radius`, `Target velocity`: target point for the guidance
- `Estimated mass`: estimated full mass of the spacecraft stack
- `Steering command`: steering command returned by the guidance algorithm
- `Target angle`: commanded rocket attitude
- `Estimate cutoff`: time till cutoff (end of guidance)
- `Delta-V`: velocity that still has to be gained
- `Current radius`: current distance from the planet surface
- `Radial velocity`: vertical velocity

- `Tangent velocity`: groundspeed

The additional table lists guidance coefficients for each of the rocket stages.



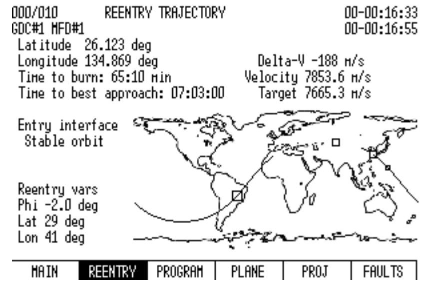
1.5.6 `REENTRY` (Reentry Trajectory)

This screen provides information about computed reentry trajectory. The reentry trajectory is updated continiously.

The following variables are listed:

- `Latitude/Longitude`: estimated landing coordinates if the de-orbit burn was to be executed just now
- `Time to burn`: time remaining to the next reentry opportunity
- `Time to best approach`: time remaining to the reentry opportunity that will bring the vessel most close to the target location
- `Delta-V`: required change in velocity for the reentry
- `Velocity`: current velocity
- `Target`: target velocity
- `Phi`: angle at which spacecraft will enter the Earth atmosphere
- `Lat/Lon`: target landing coordinates

The small map displays orbital track, and highlights remaining path to target reentry point as a red line. The small red rectangle indicates location of the landing if the burn was to be made just now.

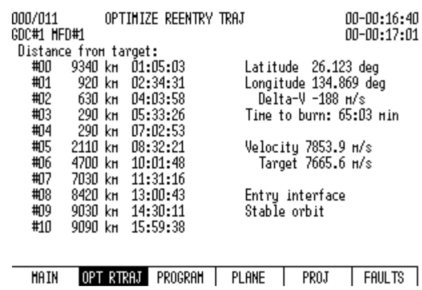


1.5.7 `OPT RTRAJ` (Optimize Reentry Trajectory)

This screen is used for optimizing the reentry trajectory for a closer approach to the target landing site. It lists estimates of distance from the landing point to target reentry point.

This table also lists time remaining until that point is reached.

All other displayed variables are the same as on the `REENTRY` screen.



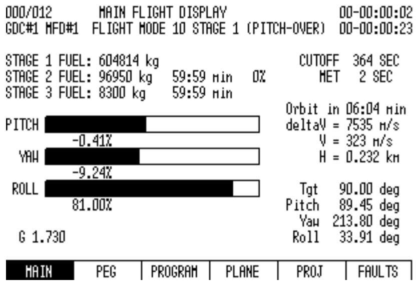
1.5.8 `MAIN` (Main Flight Display)

This display provides most important information regarding the spacecraft. It has three distinct subscreens which are most relevant to the current phase of flight:

- Ascent
- On-orbit operations
- Re-entry

During ascent this screen will display remaining fuel, target command from the guidance software, current altitude and velocity, remaining velocity.

It will also display estimate of time till cutoff, and total elapsed time.

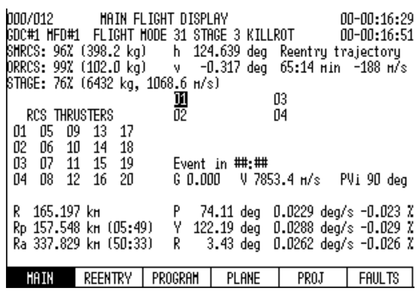


During on-orbit operations this screen displays state of all reaction control system thrusters, remaining fuel in RCS and OMS, current velocity vector.

This screen also lists rotation rates and current angles on all three axes, followed by current command (from digital autopilot, and users input).

`R` is the current altitude, while `Rp` and `Ra` are values of perigee and apogee respectively.

This screen also shows a portion of event programmer, displaying next 4 commands to be executed, and time remaining.



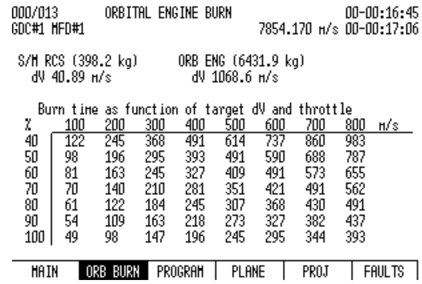
1.5.9 `ORB BURN` (Orbital Engine Burn)

This screen lists calculations related to orbital manuevering system burns. It will list remaining fuel in service module and OMS tanks, along with estimate of total delta-V available from these systems.

The table lists amount of time in seconds required to perform a target burn. It lists target change in velocity on the horizontal axis, and target throttle setting on the vertical axis.

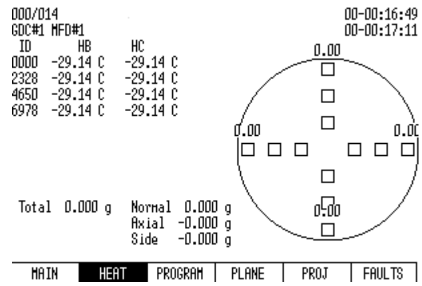
1.5.10 `HEAT` (Heat Shield Status)

Heat shield status screen will display temperature values from certain sensors located on the spacecraft bottom.



The large diagram shows estimate of temperature for all sensors and current heat flux at these points.

Heat flux is displayed in kilowatts per one square meter.



Chapter 2

Checklists

2.1 Ascent Checklists

Ascent to a pre-configured orbit

- ☐ Push `SRB IGNT`
- ☐ The rocket will execute guidance automatically
- ☐ Go to **Entry to orbit** checklist

Ascent to a custom orbit

- ☐ Push buttons on MFD to adjust target apogee, inclination
- ☐ Push `SRB IGNT`
- ☐ The rocket will execute guidance automatically
- ☐ Go to **Entry to orbit** checklist

Programmed ascent

- ☐ In this checklist apogee is 456 km, perigee is 234 km. Replace values in checklist with target orbital elements
- ☐ Select `PROGRAM` MFD screen
- ☐ Use `+` and `-` buttons to select program item 1
- ☐ Enter via keypad `222 456` (456 km)
- ☐ Press `EXEC`
- ☐ Press `+`
- ☐ Enter via keypad `642 234` (234 km)
- ☐ Press `EXEC`
- ☐ Push `SRB IGNT`
- ☐ Go to **Orbital manuevering (automatic)** checklist

2.2 On-orbit Checklists

Entry to orbit (manual)

- ☐ Wait until stage 2 burns out
- ☐ If `RCS ON` button not lit: push `RCS ON` to enable reaction control system
- ☐ Push `ATT PRO`
- ☐ Verify that spacecraft is in flightmode 32 (`ATT PRO` button lit)
- ☐ Wait until spacecraft stops adjusting attitude
- ☐ Verify that throttle is set to 0%
- ☐ Push `ORB ENGN` button to arm orbital manuevering
- ☐ Verify that `ORB ENGN` is lit, and is not flashing
- ☐ If `ORB ENGN` button is flashing, set throttle to 0
- ☐ Wait until spacecraft reaches apogee, or is past apogee
- ☐ Increase throttle to 100%
- ☐ Wait until target orbital parameters are reached
- ☐ Throttle back to 0%
- ☐ Push `ORB ENGN` button to disarm orbital manuevering
- ☐ Verify that `ORB ENGN` button is not lit
- ☐ If additional orbital manuevering is required, go to **Orbital manuevering** checklists

Entry to orbit (automatic)

- ☐ Wait until stage 2 burns out
- ☐ Select `PROGRAM` MFD screen
- ☐ Use `+` and `-` buttons to select program item 1
- ☐ Enter via keypad `222 234` (for a target perigee of 234 km)
- ☐ Press `EXEC`

Orbital manuevering (manual)

- ☐ Verify that throttle is set to 0%
- ☐ Push `ORG ENGN` button to arm orbital manuevering
- ☐ Verify that `ORB ENGN` is lit, and is not flashing
- ☐ If `ORB ENGN` button is flashing, set throttle to 0
- ☐ Increase throttle to 100%
- ☐ Wait until target orbital parameters are reached
- ☐ Throttle back to 0%
- ☐ Push `ORB ENGN` button to disarm orbital manuevering
- ☐ Verify that `ORB ENGN` button is not lit

Orbital manuevering (automatic)

- ☐ Enter corresponding command into the on-board event programmer
- ☐ Press `EXEC`

Orbital manuever: change perigee (auto)

- ☐ Enter via keypad `242 234` (for a target perigee of 234 km)
- ☐ Press `EXEC`

Orbital manuever: change apogee (auto)

- ☐ Enter via keypad `142 234` (for a target apogee of 234 km)
- ☐ Press `EXEC`

2.3 Re-entry Checklists

Ballistic reentry (manual)

- ☐ Execute **Orbital manuevering** checklists to place vessel at altitude of 150 km or higher
- ☐ Push `ATT RET`
- ☐ Verify that spacecraft orients against velocity vector
- ☐ Execute de-orbit burn until entry interface at -0.50 degrees is reached (see **Orbital manuevering (manual)** checklist)
- ☐ Push `DROP ARM`
- ☐ Push `DROP STAGE` to separate service module
- ☐ The spacecraft will execute the rest of the descent automatically

Ballistic reentry (automatic)

- ☐ Execute **Orbital manuevering** checklists to place vessel at altitude of 150 km or higher
- ☐ At least 5 minutes prior to re-entry enter via keypad `431` (execute de-orbit burn)
- ☐ Press `EXEC`
- ☐ Press `+`
- ☐ Enter via keypad `3F1 7193` (detach service module at entry interface)
- ☐ Press `EXEC`
- ☐ The spacecraft will execute the rest of the descent automatically

2.4 Operation Limitations

- Do not reenter with entry interface angle of higher than -0.5 degrees
- Do not reenter with entry interface angle of lower than -2.5 degrees
- Do not descend below entry interface with service module still attached
- Always verify computer state after reboot
- Always disarm orbital engines after use
- Always detach service module before or at entry interface (120 km)

Chapter 3

On-board Computer Programming

3.1 General Description

The flight can be automated using the on-board programmable event controller. The event controller state can be verified using `PROGRAM` MFD screen. Command entry is performed using the command entry keypad.

The programmable event controller allows one to specify a certain command to be executed when certain event is reached. The command is specified as a three-digit hexadecimal number, which may be followed by a single parameter.

Commands are entered using the keyboard. To enter the next command, you need to push `+` key (`-` key will go back one step). After entering the commands into the computer press "EXEC".

3.2 Command Format

First digit specifies what event must trigger the command:

Digit	Timer name
`0`	Never trigger
`1`	At perigee
`2`	At apogee
`3`	When entering atmosphere
`4`	When reentry burn must be made
`5`	Using custom timer
`6`	Nearest perigee or apogee
`F`	Execute event as soon as possible

Note: after second stage separation the apogee timer (`2`) will always precede perigee. If the spacecraft detaches from second stage past actual apogee the apogee timer will be reset to 2 minutes.

Second digit switches autopilot mode or selects special command:

Digit	Autopilot mode
`0`	Disable autopilot
`1`	KILL ROT (removes rotation)
`2`	ATT PRO (prograde attitude)
`3`	ATT RET (retrograde attitude)
`4`	AUTO (automatic attitude)
`F`	Do not change mode, execute a special command

Attitude command will be issued 5 minutes prior to event trigger time.

The automatic attitude will be set according to the following logic:

Reason	Mode
Target burn `2 SMA TRANS`, spacecraft approaches apogee, target altitude higher than perigee	`ATT PRO`
Target burn `2 SMA TRANS`, spacecraft approaches apogee, target altitude lower than perigee	`ATT RET`
Target burn `2 SMA TRANS`, spacecraft approaches perigee, target altitude higher than apogee	`ATT PRO`
Target burn `2 SMA TRANS`, spacecraft approaches perigee, target altitude lower than apogee	`ATT RET`

If second digit is not `F`, then third digit indicates burn type, otherwise it's a special command:

Digit	Burn type
`x0`	Specific delta-V (parameter in $\frac{m}{s}$)
`x1`	Delta-v to enter atmosphere
`x2`	Semimajor transfer burn (parameter in km)
`xF`	Do not do any burn
`F0`	Set custom timer (parameter in seconds)
`F1`	Drop third stage (security code is `7193`)

Semimajor transfer burn (`SMA TRANS`) is used to change orbital elements. The parameter passed to this event is the target height of the apogee or perigee.

3.3 Controlling Internal Variables

It is possible to adjust current flight program of the guidance computer. To change a variable the `ITEM` button must be pressed, followed by index of the variable, a value sign (`+` or `-`), and the target value for this variable.

These are the variables that can be adjusted:

Index	Default	Description
1	-0.50	Phi (angle at which the spacecraft will reenter atmosphere, typically between -0.2 and -2.5)
2	Undefined	Target landing site latitude
3	Undefined	Target landing site longitude
4	250	Target apogee (for the initial ascent guidance), in km
5	-10	Target perigee (for the initial ascent guidance), in km
6	45	Target inclination in degrees
7	135	Target true anomaly (180 ends guidance at apogee, 135 will end guidance slightly prior to apogee)
8	120	Altitude of the entry interface (what the guidance system considers to be edge of atmosphere), in km

3.4 Command Reference

This section lists most common and useful commands for the event controller.

Command	Description
`000`	Clears currently entered command
`431`	Reentry burn (reentry for the selected region of the planet)
`220 12`	Increase velocity by 12 $\frac{m}{s}$ at apogee)
`FF1 600`	Set custom timer to 600 seconds (10 minutes)
`50F`	Reset autopilot to `IDLE` after custom timer expires
`3F1 7193`	Detach service module at entry interface
`342 567` twice	Make the orbit circular at altitude of approximately 567 km (may not be possible due to non-spherical Earth)
`ITEM 1 -1.00`	Set target re-entry angle to -1.0 degrees