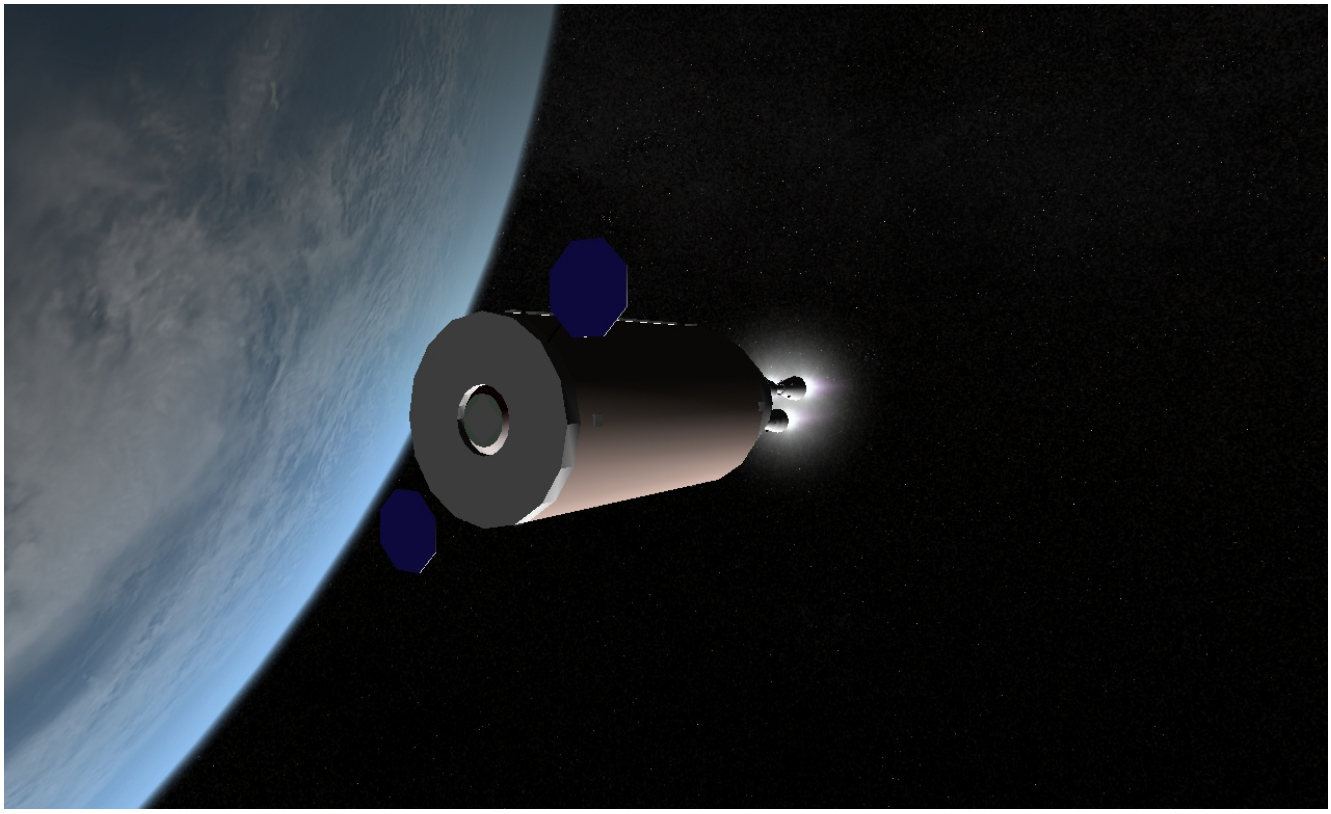
NTR core propulsion stage (Aug.21 2011, build 8) by wishbone



This is the notional core propulsion stage from Mars DRA 5.0.

Acknowledgements

Martin Schweiger for the Orbiter simulation environment, HST and ShuttlePB boilerplates which I (ab)used.
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All errors are mine. The code (insofar as it is written by me and not anybody else) is public, see notes attached to code snippets for extra limitations. This is work in progress, so some things may not always go as planned. Formulas are common knowledge…

Changelog

Build 8: August 21, 2011

Added loadable command scripts. Enhanced set of commands available through Alt-C. First attempt to texture the NTR core stage. When attitude autopilots are active, time acceleration is limited to 10x.

Build 7: June 18, 2011

Partially implemented a smoother DAP from COLOSSUS for large maneuvers. Added indication of power generation by the solar arrays. Changed command set. Added rate deadbands. More stuff can be saved and re-loaded. Added power control HUD page. Implemented boil-off, solar radiation and planetary albedo and IR heatloads. Sample fairings are shipped as FairingCz_1.msh and FairingCz_2.msh in the Meshes directory.

Build 6: June 14, 2011

Fixed excessive default gains. Added liquid H2 tank as a separate vehicle. Added sun and point tracking AP. Made more things configurable and re-loadable.

Build 5: May 17, 2011

RCS DAP can now manage a stack of docked/attached vessels. A 20 sec ullage burn added. DAP channels selectable. DAP config screen with adjustable gains added. Sunward attitude error computed and displayed. Solar battery deployment status displayed in the HUD. Visual artefacts mostly eliminated. Beacons added. RCS location tweaked, 3 more forward RCS thrusters and 1 more retro RCS thruster added, with somewhat tweaked locations.

Build 4: May 13, 2011

Launch and checkout modes implemented, solar panels are animated, engines uprated to 111 kN; self-destruct behaviour added.

Build 3: May 11, 2011

Thrust vectoring, attitude rate nulling added. RCS locations tweaked, exhausts added. Auto-cutoff implemented. State is mostly saved (with the exception of gimballing and rate nulling regime). Auto-refuelling from tanks no.0 of all docked and attached vessels.

Build 2: May 8, 2011

CoG and PMI change as the propellant is depleted. See you on Mars!

Installation and requirements

Installation is simple: just un-zip the archive into your **Orbiter 2010** directory.

Technical data

NTR core propulsion stage

Dimensions:

Length: 27.3 m

Diameter: 9.02 m (without solar arrays)

Docking port: 1 (forward)

Engines:

3 Nuclear thermal rocket 2-axis gimballed engines, 111 kN each, Isp 819 s (Liquid H_2)

6 turbopump assemblies (2 per engine) – cross-linked (not implemented)

18 RCS thrusters, 200 N each, Isp 320 s (Monomethylhydrazine + N_2O_4)

Dry mass: 33.7 tonnes

Propellant mass:

LH_2 — 59.4 tonnes, stored in a cryo-tank of 4.4 meters radius, √2/2 ends and 13.6 meters cylinder length, wrapped in 220 layers (unrealistic!) of MLI with no trapped gas and equivalent effective conductivity of 0.00001 W/(m*K)
RCS propellants — 3.6 tonnes

Zero-boiloff cryocooler (275 W of input per 1 W of heat leak reduction, minimum power 2.6 kW, maximum power 7.0 kW)
Command and data handling unit (7W power consumption)
Fuel pumps
Electrical systems: 2 PV arrays (multi-junction), area - 22.6 sq.m, which are unfurled at checkout in stable LEO (about 6kW at LEO), Li-Ion batteries (3200 W-h).

NTR LH2 inline tank

Dimensions:
Length: 16.3 m
Diameter: 9.02 m (without solar arrays)

Docking port: 2 (forward and aft)
Engines:
18 RCS thrusters, 50 N each, Isp 150 s (Cold boiloff hydrogen gas thrusters)

Dry mass: 21.4 tonnes
Propellant mass:
LH_2 — 69.9 tonnes
RCS propellant — 100 kg (notional amount for attitude control while in free flight!)

Zero-boiloff cryocoolers (not implemented)
Fuel pumps – TBD
Electrical systems: 2 auxiliary PV arrays which are unfurled at checkout in stable LEO (but do not currently provide electricity), Li-Ion batteries

Operation

NTR core propulsion stage

If you want to launch the craft, please consider that you should put it into an orbit with PeA>=280 km and ApA<=420 km to be able to activate the reactors and RCS engines.

Self-destruct behaviour is triggered by increasing static pressure or g-loads higher than 7 g in Launch mode, and dynamic pressure > 1kPa in Checkout and Normal modes. If your craft vanishes, check Orbiter.log.

Before burn, align the stage/stack carefully. All management is done from the glass cockpit (there is no virtual cockpit in an unmanned stage!) Press Alt-M to enter target dV (the engines will cut off automatically once this dV value is reached).

NTR (nuclear thermal rocket) engine is started by applying main thrust (pressing the Numpad + key). The three reactors are ramped up until nominal thrust of 111 kN per engine. You can initiate shutdown at any time by pressing Ctrl-K. Please note it takes time, and the full dV at engine shutdown is displayed on the HUD.

If there is not enough fuel to complete shutdown the reactors will experience meltdown. Nothing tragic at this time, but you won't be able to fire them again.

After shutdown the reactor is poisoned by Xenon-135, and will not start up again until Xe-135 poisoning level goes below 5% (otherwise control drums will not have enough reactivity to achieve nominal operation).

RCS for the vessel is kinda slow, but realistic (uses nasty hypergolic bi-propellant). Default Orbiter autopilots are buggy and will not handle it gracefully. Upon burn initiation, you can use thrust vectoring in pitch and yaw, or engage automatic attitude rate nulling.

Press Alt-L to toggle DAP on and off (DAP uses RCS when the engines are off, and TVC when they are operating). Use arrows to select rates for pitch and yaw, and Insert/Delete keys to set roll rate. If the stage is docked or attached to other vessels, each toggling of Alt-L will re-optimize thruster firings and use all available RCS thrusters, if necessary, to achieve zero linear force rotation. This re-optimization is predicated on RECOMPUTE RCS AUTO flag being displayed in DAP CONFIG page. If you want, you can issue RECOMPUTE RCS MANUAL command and then set up your own RCS strings by Alt-C AUTO RCS SET commands. Please note that you won't be able to use LH2 tanks' weak cold boiloff gas RCS for automatic or manual RCS re-strings once your NTR propulsion stage is docked to them.

Alt-S will automatically track the Sun. This autopilot is not optimal, and requires reconfiguration via DAP CONFIG once another vehicle is added to the stack.

Alt-P will aim the stack at a given point in J2000 stellar coordinates (please enter Right ascension and declination of the aimpoint).

By pressing Ctrl-1 (pitch), Ctrl-2 (yaw) or Ctrl-3 (roll) (top row of main keyboard, you can toggle individual DAP channels on and off.

Press Ctrl-Y to cycle through HUD pages (DAP CONFIG, ENGINE CONTROL, POWER CONTROL).

With DAP off, you can move 1, 2, or 3 engines in pitch and yaw, by first selecting engines to be controlled (by pressing Alt-1 (top row of main keyboard), Alt-2, Alt-3), and then using arrow keys to move the engines 0.1 degree at a time. You can deselect all engines by pressing Alt-8 (gimbal settings are not changed). To deselect and reset all engines to their initial positions, press Alt-0.

UNSUPPORTED FEATURES: K key will move solar panels. Alt-4 and Alt-5 (while the main engines are burning) could be used for rolling the craft by gimballing the engines.

You can dock any vessel to the core stage's front docking port, and the stage will automatically use propellant from docked or attached vessels' tanks No. "0", enabling realistic trans-martian injections.

Beacons are activated in checkout mode, and switched off after docking. You can turn them on and off through the BEACONS ON/BEACONS OFF commands.

List of commands accessible via Alt-C (not case-sensitive)

Command	Meaning
TVC PITCH PROP {proportional gain}	Set autopilot gains
TVC PITCH INT {integral gain}	
TVC PITCH DERIV {derivative gain}	
TVC YAW PROP {proportional gain}	
TVC YAW INT {integral gain}	

TVC YAW DERIV {derivative gain}	
RCS PITCH PROP {proportional gain}	
RCS PITCH INT {integral gain}	
RCS PITCH DERIV {derivative gain}	
RCS YAW PROP {proportional gain}	
RCS YAW INT {integral gain}	
RCS YAW DERIV {derivative gain}	
RCS ROLL PROP {proportional gain}	
RCS ROLL INT {integral gain}	
RCS ROLL DERIV {derivative gain}	
AUTO RCS ENABLE	Turn on/off use of stack-wise (computed or manually entered) RCS strings by DAP
AUTO RCS INHIBIT	
RECOMPUTE RCS AUTO	Turn on/off re-computation of stack-wise RCS strings
RECOMPUTE RCS MANUAL	
AUTO RCS SET {rcs string}	Manually input an RCS string (will be overridden if set to RECOMPUTE RCS AUTO)
AUTO RCS LEVEL {rcs torque (in N·m) or force (in N)}	Set torque/force for the automatic stack RCS optimization routine
ATT DB PITCH {attitude deadband, deg.}	Set DAP attitude deadbands (WORK IN PROGRESS!)
ATT DB YAW { attitude deadband, deg.}	
ATT DB ROLL {attitude deadband, deg.}	
RATE DB PITCH {rate deadband, deg./sec.}	Set DAP rate deadbands (WORK IN PROGRESS!)
RATE DB YAW {rate deadband, deg./sec.}	
RATE DB ROLL {rate deadband, deg./sec.}	
BEACONS ON	Turn beacons on (not saved)
BEACONS OFF	Turn beacons off (not saved)
DISCHARGE THRESHOLD {desired power consumption during eclipse, W}	Operate cryocooler power setpoint (TBD)
PDOT {pitching rate, deg/sec}	Command pitch maneuver
YDOT {yaw rate, deg/sec}	Command yaw maneuver
RDOT {roll rate, deg/sec}	Command roll maneuver
SHUTDOWN NOW	SCRAM!
SHUTDOWN AT DV {dV at engine cut-off, in m/s}	Shut down reactors to achieve burn dV around stated value (you may have to use translation RCS a few times to correct for minor timing errors)
TRACK QUAT {q0} {q1} {q2} {q3}	Rotate to commanded attitude (stated as a quaternion)
TRACK EULER {a1} {a2} {a3}	Rotate to commanded attitude (stated as three Euler angles)
TRACK SUN ON	Toggle Sun tracking autopilot on
TRACK SUN OFF	Toggle Sun tracking autopilot off
BURN FOR DV {dV at engine cut-off, in m/s}	Initiate ullage burn and main engines' burn (currently dV calculations are somewhat hazy about the effects of ullage burn on the craft)
LOAD COMMANDS {name of command script}	Load and execute a command script – see format for details

Manual RCS string format

```
rcs_string := thruster_group:thruster_definition+
thruster_definition := spacecraft_name:thruster_id:thrust_setting
thruster group := UP|DN|FW|BK|LF|RT|P-|P+|B-|B+|Y-|Y+
```

`thrust_setting` is a number between 0.0 and 1.0
`spacecraft_name` is the name of the spacecraft (it is assumed it does not contain colons!)
`thruster_id` is the consecutive (zero-based) index of the RCS thruster as it is defined by the vessel. Neither main, nor retro nor hover engines are allowed.

Examples

```
DN:NTR1:4:1.000:NTR1:5:1.000:NTR1:6:0.313:NTR1:7:0.313:NTR1:8:1.000:NTR1:9:1.000
P-:NTR1:5:0.000:NTR1:7:0.556:NTR1:10:0.556
B+:NTR1:5:0.000:NTR1:9:0.556:NTR1:10:0.556
FW:NTR1:4:0.530:NTR1:5:0.530:NTR1:6:0.999:NTR1:7:1.000:NTR1:8:0.530:NTR1:9:0.530
UP:NTR1:4:1.000:NTR1:5:1.000:NTR1:6:0.313:NTR1:7:0.313:NTR1:8:1.000:NTR1:9:1.000
LF:NTR1:4:1.000:NTR1:5:1.000:NTR1:6:0.313:NTR1:7:0.313:NTR1:8:1.000:NTR1:9:1.000
P+:NTR1:4:0.000:NTR1:6:0.556:NTR1:11:0.556
Y-:NTR1:17:0.556:NTR1:18:0.000:NTR1:20:0.556
B-:NTR1:4:0.000:NTR1:8:0.556:NTR1:11:0.556
BK:NTR1:4:1.000:NTR1:5:1.000:NTR1:6:0.313:NTR1:7:0.313:NTR1:8:1.000:NTR1:9:1.000
RT:NTR1:4:1.000:NTR1:5:1.000:NTR1:6:0.313:NTR1:7:0.313:NTR1:8:1.000:NTR1:9:1.000
Y+:NTR1:6:0.000:NTR1:9:0.000:NTR1:13:0.309:NTR1:14:0.309:NTR1:16:0.246:NTR1:21:0.246
```

Command script format

Command script (directory defaults to root Orbiter directory) can contain comments (first character should be a semicolon) and space-delimited pairs of MJD (modified Julian day) values and command strings. At loading, all commands with times less than current simulation MJD value are executed. In the bottom of ENGINE CONTROL screen there are displayed number of commands in the queue and the next command to be executed.

Examples

```
; This is a comment
51986.2853 BEACONS OFF
51986.2859 TRACK EULERS 20 30 40
51986.2934 BURN FOR DV 820.3
51986.39411 TRACK SUN
```

NTR inline LH_2 tank

Usual Orbiter keys for attitude control to stabilize the vessel prior to docking. Nothing else at the moment.

Enjoy!

Known bugs and shortcomings

- Sun tracker DAP consumes too much fuel at high time compression levels (and possibly, in lower, too)
- Autopilot is not perfect
- The initial mesh starts with solar panels deployed (reported by PeterRoss, confirmed, not yet fixed)
- No reactor/TPA failure simulation.
- No realistic Isp dependence on temperature (the formula is there!).
- Not modelling reactor's thermal power explicitly.
- No antennas.