ORBITER
Space Shuttle Implementation

www.medphys.ucl.ac.uk/~martins/orbit/orbit.html

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1. Introduction

This document contains details of the implementation of the Space Shuttle (Atlantis) vessel class implementation in ORBITER. The module code is available in the samples\Atlantis subdirectory of the SDK. The pysical parameters discussed here are the values used by ORBITER, as I collected them from public sources, and may deviate from the actual Space Shuttle characteristica. It is my goal to model the shuttle performance as close to life as possible, so if you have corrections to parameters or procedures, please get in contact.

2. Mesh-derived parameters

The following parameters were derived directly by analysing the meshes:

Orbiter

Length:	39.16 m	
Wingspan:	24.54 m	
Height:	14.29 m	
Volume:	1133 m^3	
Cross-sections:	234.8 m^2	(projection on yz-plane: side-on)
	389.1 m^2	(projection on xz-plane: top-down)
	68.2 m^2	(projection on xy-plane: head-on)
PMI[a]:	78.2/82.1/10.7 m^2	

Tank[b]

Length:	47.83 m	
Diameter:	9.68 m	
Volume:	2829 m^3	
Cross-sections:	412.1 m^2	(projection on yz-plane: side-on)
	411.8 m^2	(projection on xz-plane: top-down)
	72.7 m^2	(projection on xy-plane: head-on)
PMI[a]:	145.6/145.6/10.5 m^2	

SRB

Length:	45.7 m	
Diameter:	3.8 m	(tube) 5.9 m (max)
Volume:	452 m^3	
Cross-sections:	162.1 m^2	(projection on yz-plane: side-on)
	162.1 m^2	(projection on xz-plane: top-down)
	26.6 m^2	(projection on xy-plane: head-on)
PMI[a]:	154.3/154.3/1.83 m^2	

Orbiter+Tank assembly

Length:	57.55 m	
Height:	24.44 m	
Volume:	3962 m^3	
Cross-sections:	646.2 m^2	(projection on yz-plane: side-on)
	597.5 m^2	(projection on xz-plane: top-down)
	140.0 m^2	(projection on xy-plane: head-on)
PMI[a]:	173.3/161.0/24.0 m^2	

Orbiter+Tank+SRBs (launch assembly)

Length:	57.91 m	
Height:	24.44 m	
Volume:	4868 m^3	
Cross-sections:	687.4 m^2	(projection on yz-plane: side-on)
	849.5 m^2	(projection on xz-plane: top-down)
	189.4 m^2	(projection on xy-plane: head-on)
PMI[a]:	179.1/176.8/29.3 m^2	

[a]: principal moments of intertia tensor, mass-normalised, assuming homogeneous density distribution
[b]: including Orbiter mount brackets

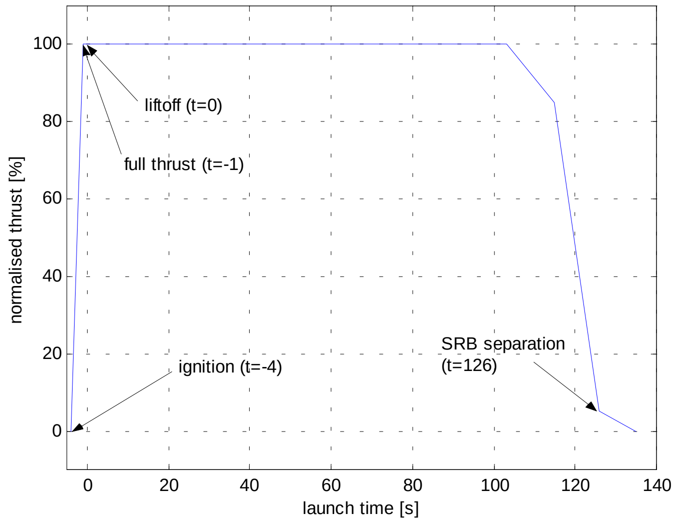
3. SRB thrust characteristics

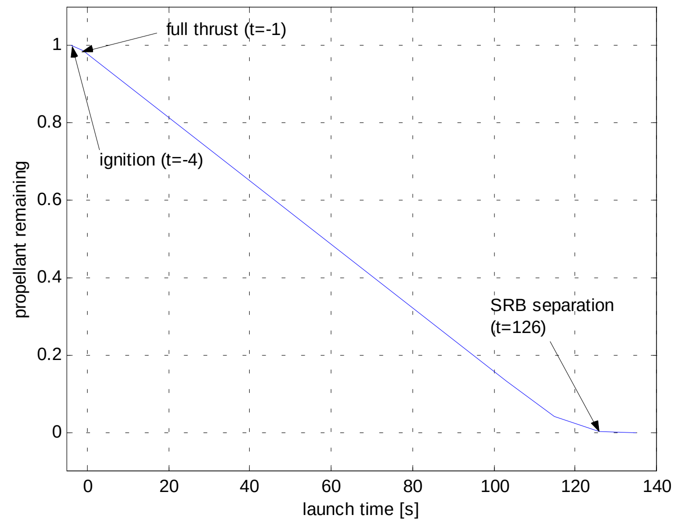
The following parameters are used for the solid rocket boosters (per unit):

Thrust at liftoff:	$1.17918 \cdot 10^7$ N	
SRB separation:	126 s	after liftoff
Weight empty:	87543 kg	
Weight propellant:	502126 kg	

The following (largely fictional) piecewise linear functions for thrust rate and propellant level as a function of burn time are assumed (liftoff time t=0)

Time [s]	-4	-1	103	115	126 (sep.)	135
Thrust [%]	0	100	100	85	5	0
Propellant [%]	100	98.768	13.365	4.250	0.185	0





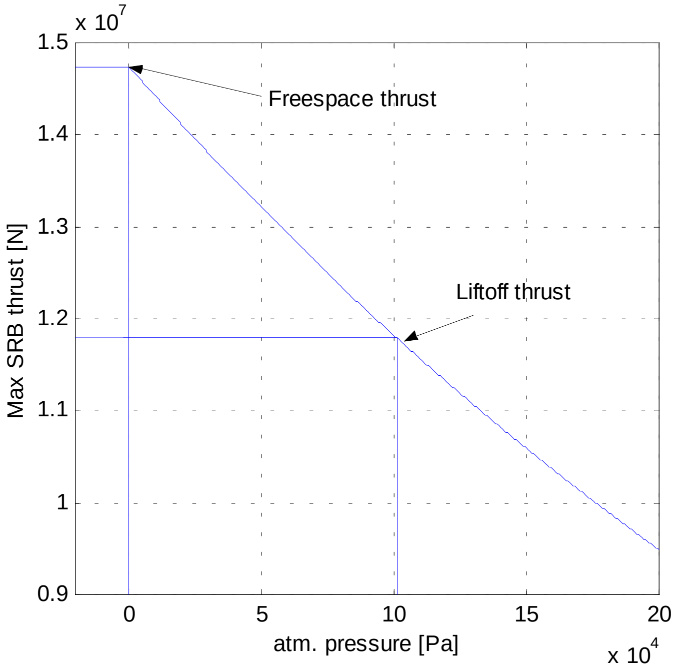
From this table, the value derived for the fuel-specific impulse (ISP), i.e. the amount of thrust obtained from burning 1kg of propellant per second, is

ISP = 2859.74 m/s (at liftoff)

The actual maximum thrust also depends on the ambient atmospheric pressure. We assume that the freespace thrust is 1.25 times the thrust at (Earth) liftoff, with an exponential pressure relationship of the following form:

$F = F_\infty \exp(-p\,\beta)$ with $\beta = -1/p_0 \log(F_0/F_\infty)$

where p_0 is the pressure at liftoff altitude, p is the current pressure, and F_0 and F_∞ are the liftoff and freespace thrust ratings, respectively.



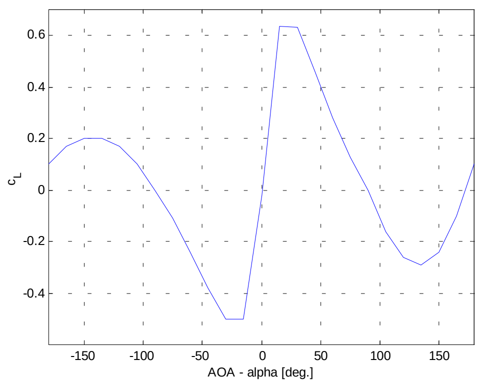
Problems:

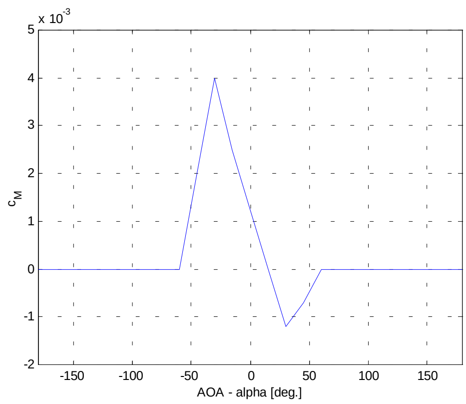
- The thrust curve during the burnout stage is not based on any data. In particular the amount of thrust produced at separation (t=126) is not known.
- According to sources, the SRB's reduce thrust by 1/3 after 50 s to keep acceleration within limits. This is not currently modelled.
- The pressure-thrust relationship is assumed, not backed by any data.

4. Orbiter aerodynamic characteristics

The Atlantis orbiter uses the following subsonic lift and moment coefficients:

1.1 Vertical lift component – wings and body

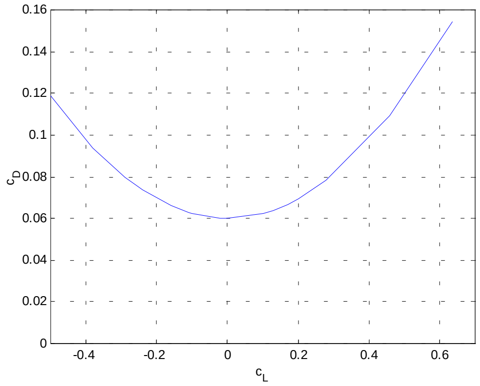




The lift profile utilises a documented lift slope of 0.0437/deg. Everything else is rather ad-hoc. In particular the moment coefficient profile needs more thought. Other parameters:

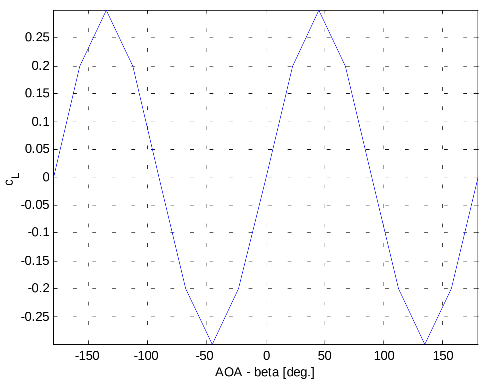
Zero-lift drag	$c_{D,0} = 0.06$
Chord length	c = 20 m
Reference area	S = 270 m^2
Wing aspect ratio	A = 2.266
Oswald efficiency factor	ε = 0.6

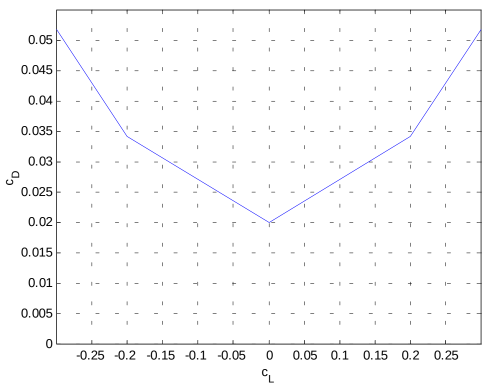
This produces the following drag polar:



1.2 Horizontal lift component – vertical stabiliser and body

Lift coefficient and drag polar for the horizontal lift component (produced by the orbiter body and vertical stabiliser) are given by:





The horizontal lift profile is symmetric (symmetric airfoil). Other parameters:

Moment coefficient	$c_M = 0$
Zero-lift drag	$c_{D,0} = 0.02$
Chord length	c = 20 m
Reference area	S = 50 m^2
Wing aspect ratio	A = 1.5
Oswald efficiency factor	ε = 0.6

1.3 Speed brake

The split-rudder speed brake is activated with Ctrl-S. Deployment time is 4.93 seconds. At full extent, the brake will generate a subsonic drag force of 5.0m^2 q_∞ (q_∞: freestream dynamic pressure) in Orbiter. It will also generate a pitch-up moment.