Trajectory Parameters & Rocket Design

Basic Trajectory Tools

Topics covered so far have **provided** a few of the **tools** to help synthesize a **trajectory.**

Of course, it is **clear** that a realistic **trajectory** would include many more **aspects** (e.g. earth's curvature & rotation, geographical information etc.).

However, for **initial** ascent mission **design**, simplified solutions **provide** reasonable trajectory **estimates.**

Orbit – Trajectory Connection

It is to be **noted** here that **orbit** requirements **decide** the terminal **trajectory** parameters of an **ascent** mission.

In this context, while, **orbits** explicitly **depend** only on **terminal** parameters, as trajectory itself **impacts** terminal parameters, **orbits** also get **influenced.**

Therefore, in a **realistic** scenario, **optimization** is used to **arrive** at trajectory for **best** terminal values.

Trajectory – Rocket Connection

As **trajectory** solution is a **combination** of mission and vehicle, **rocket design** becomes part of trajectory **design.**

In fact, in **most** cases, trajectory and **rocket** are designed **together** through a **multi-disciplinary** approach.

However, in order to **understand** features of this **exercise**, we adopt a **simpler** strategy to design a **rocket**.

Rocket Configuration Design Basics

Rocket – Trajectory Requirements

For **rocket design** task, we take note of **ideal** burnout concept, which is the **best** possible performance that a **rocket** – trajectory combination can **deliver.**

In addition, we **realize** the fact that **ideal** burnout is **related** to actual performance **through** gravity and drag **loss** models and, hence, to actual **orbital** missions.

Thus, we employ **ideal** burnout concept to **design** both **rocket** and trajectory, for specified **orbital** missions.

Orbit – Trajectory – Rocket Design

Let us **consider** an orbital **mission** to have a **circular** orbit at **250 km** above earth's surface (i.e. **space station**).

This means (to be shown later) that we **need** a velocity of **~7.76** km/s, which is **parallel** to local horizon.

Assuming that we **minimize** the losses through **optimal** design principles, we will still have to **account** for around **15%** energy loss **due** to gravity and drag.

Orbit – Trajectory – Rocket Design

Therefore, in order to **achieve** actual energy of $\mathbf{3.25\times10^7}$ at burnout, we need **ideal** energy of $\mathbf{3.82\times10^7}$, which corresponds to **ideal** velocity of **8.75 km/s.**

This can be **done** as follows.

$$m_b = m_0 e^{-\frac{891.9}{I_{sp}}}; \quad m_b \rightarrow \text{ Mission Payload(?)}$$

Here, we **note** that mass at the **end** of the burnout is not the **actual** mission payload, but additional **structural** mass that is part of the **payload** and needs to be **shed**.

Orbit – Trajectory – Rocket Design

Here, it is to be **mentioned** that solution so obtained **assumes** that all the **propellant** is burnt is a **single** shot.

Such rockets are **single** stage rockets and are commonly **employed** to launch **small-sized** spacecraft.

We find that such a **process** results in a **simple** rocket configuration, which can then be **used** to generate the **applicable** trajectory under realistic **environment.**

Single Stage Rocket Features

A **single** stage rocket **burns** all propellant in **one go**, leading to the **situation** where the **empty shell** of rocket motor is **carried** till the **last** moment of burnout.

As seen earlier, **energies** imparted to **shell** as well as to **unburnt** propellant are a complete **loss** to the payload.

Typically, single stage **payload** fractions are of the order of **0.001**, making the **overall** mission quite **inefficient,** and **Multi-stage** rockets **aim** to address this **deficiency.**

Summary

Therefore, to **summarize**, design of rocket at the **initial** stage is driven primarily by **two** considerations; the **terminal** parameters and payload mass **fraction**.

Also we **note** that this can be adequately **achieved** by using the ideal **velocity** expression, together with the broad estimate of the **losses** likely during the mission.