

Kepler's Law

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October 12, 2024

Abstract

Kepler's law is a cornerstone of orbital mechanics.

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1 Overview

Kepler's law is a cornerstone of orbital mechanics.

1. env
2. ldd

2 Geometry of Kepler's Law

Disagreement with this YouTuber True Anomaly vs. Mean Anomaly

3 Mathematics

3.1 Definitions

Definition 1 (The ellipse). *Given $\theta \in [0, 2\pi)$, and parameters $a, b \in \mathbb{R}^+$ with $a > b$ the following parametric form defines an ellipse.*

$$\epsilon(\theta) = (a \cos \theta, b \sin \theta) \tag{1}$$

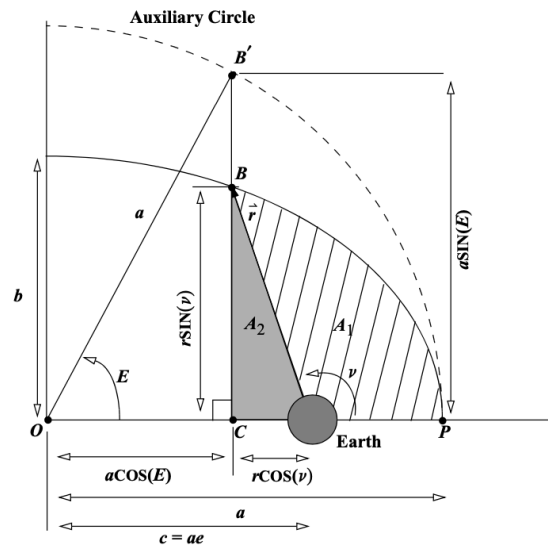


Figure 2-2. **Geometry of Kepler's Equation.** The eccentric anomaly uses an auxiliary circle as shown. The ultimate goal is to determine the area, A_1 , which allows us to calculate the time.

Figure 1: Vallado's figure 2-2 showing E and ν .

Sec 4.2 TIME-OF-FLIGHT – ECCENTRIC ANOMALY 183

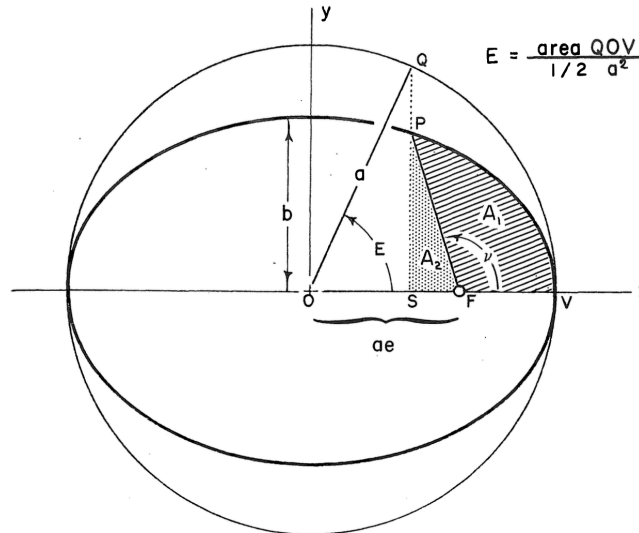


Figure 4.2-2 Eccentric anomaly, E

Figure 2: Figure 4-4 in Bate *et al.* showing E and ν .

ACQ will be defined as the eccentric anomaly, E , and it will be shown that the relation between M and E is given by Kepler's equation.

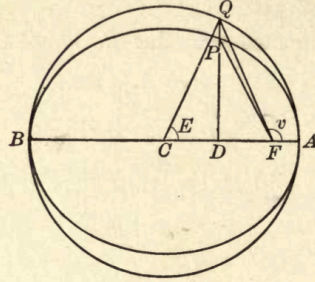


Fig. 28.

From the law of areas and the properties of the auxiliary circle, it follows that

$$\frac{M}{2\pi} = \frac{\text{area } AFP}{\text{area ellipse}} = \frac{\text{area } AFQ}{\text{area circle}}.$$

$$\text{Area } AFQ = \text{area } ACQ - \text{area } FCQ = \frac{a^2 E}{2} - \frac{a}{2} ae \sin E.$$

Therefore

$$\frac{M}{2\pi} = \frac{a^2}{2} \frac{(E - e \sin E)}{\pi a^2};$$

or,

$$\begin{cases} M = E - e \sin E, \\ FP = r = \frac{a(1 - e^2)}{1 + e \cos v} = \sqrt{PD^2 + FD^2} = a(1 - e \cos E), \end{cases}$$

Figure 3: Moulton's figure 28 showing E and ν .

Definition 2 (Eccentricity of the ellipse). *The eccentricity is a scalar parameter $e \in (0, 1)$ and can be expressed in terms of fundamental parameters of the ellipse where $a > b$ as*

$$e = \frac{c}{a} = \sqrt{1 - \left(\frac{b}{a}\right)^2} \quad (2)$$

Definition 3 (Mean anomaly). *Kepler's Law¹ defines the mean anomaly as the angular measure $M(e, E) : (0, 1) \times [0, 2\pi) \mapsto [0, 2\pi)$ as*

$$M(e, E) = E - e \sin E \quad (3)$$

Theorem 4 (Continuity of the mean anomaly). *The mean anomaly as defined in definition 3 is a continuous function.*

Proof. To prove continuity show that for any two points p and q in the domain there exists a majorization constant K such that

$$M(p) - M(q) \leq K|p - q| \quad (4)$$

Spoiler alert: the majorization constant is 2π . □

Observation: given the continuity of the mean anomaly, one may use Newton's method Gautschi 2011, §4.6 to solve the nonlinear equation.

References

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Vallado, D.A. (2022). *Fundamentals of Astrodynamics and Applications*. 5th ed. Microcosm Press;

¹Bate et al. 2020, eq 4.5 Moulton 1970, p.159 Vallado 2022, §2.2, Kaula 2013, pp. 3–19