CLASSICAL ORBITAL ELEMENTS

9/25/17

TRAJECTORY | POLAR EQ – $r = \frac{p}{1+e\cos\theta}$

- GIVES US THE POSITION | VELOCITY WITHIN ORBITAL PLANE.
  - SHOW SOME EXAMPLE ORBITAL PLOTS
- EVERYTHING IS DEFINED IN THE ORBIT PLANE 2D.
- NOW WANT TO MOVE TO 3D
  - NEED SOME BACKGROUND TO DEFINE ORBIT IN SPACE
- THE FIRST STEP IS TO DEFINE THE COORDINATE SYS. MANY ARE AVAILABLE

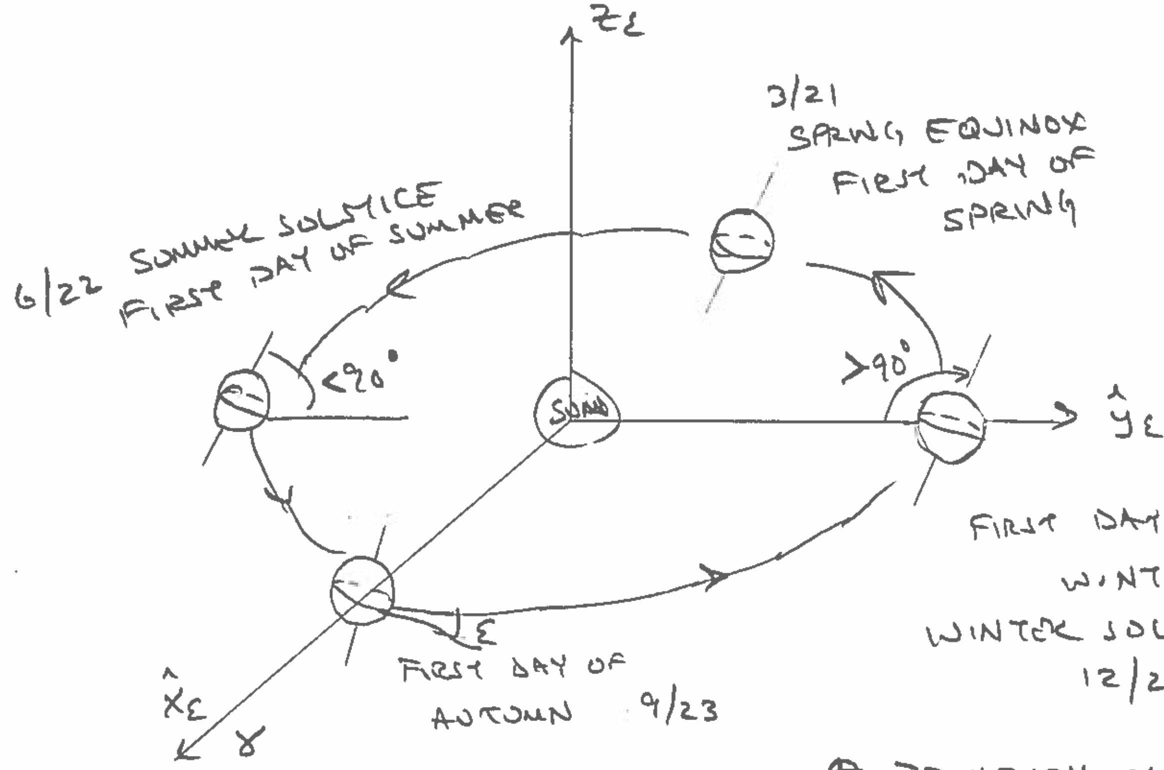
1. ECLIPTIC SYSTEM – FUNDAMENTAL PLANE IS THE EARTH'S ORBIT AROUND THE SUN $\hat{x}_\varepsilon, \hat{y}_\varepsilon$
2. EQUATORIAL SYSTEM – FUNDAMENTAL PLANE IS THE BODY'S EQUATOR $\hat{x}, \hat{y}$

OBLIQUITY OF THE ECLIPTIC (ε) – INCLINATION OF ECLIPTIC WRT TO EQUATOR

$$\varepsilon_\oplus \approx 23.5^\circ$$

TO EFFECTIVELY USE A COORDINATE SYSTEM, REF. DIRECTIONS MUST BE DEFINED – NEED A FIXED DIRECTION IN FUNDAMENTAL PLANE FROM WHICH MEASUREMENTS ARE MADE

→ VERNAL EQUINOX – $\hat{x}_\varepsilon = \hat{x}$ INTERSECTION OF ECLIPTIC + EARTH EQUATORIAL



VERNAL EQUINOX

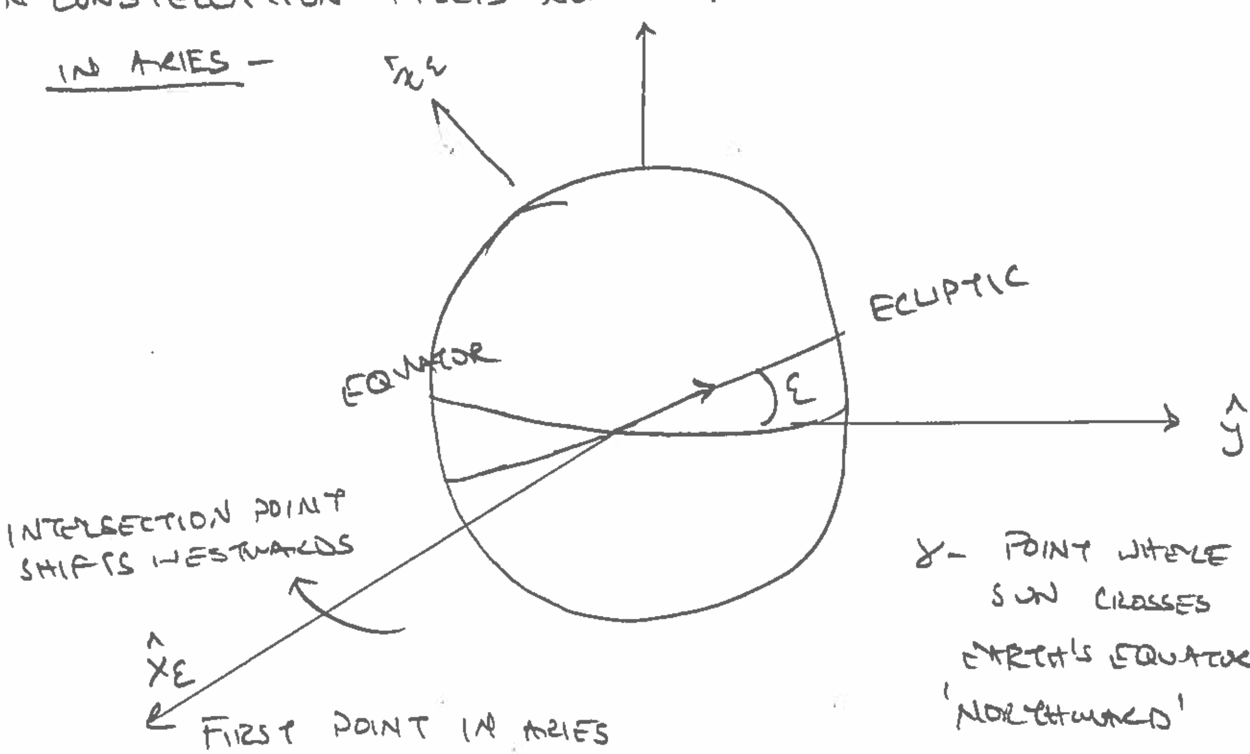
FIRST POINT IN ARIES

⊕ PERIHELION ~ JAN 4.

EARTH ORBIT NEARLY CIRCULAR: AXIS OF ROTATION WRT
ECLIPTIC ≈ 23.5°

EQUINOX – LENGTH OF DAY|NIGHT EQUAL

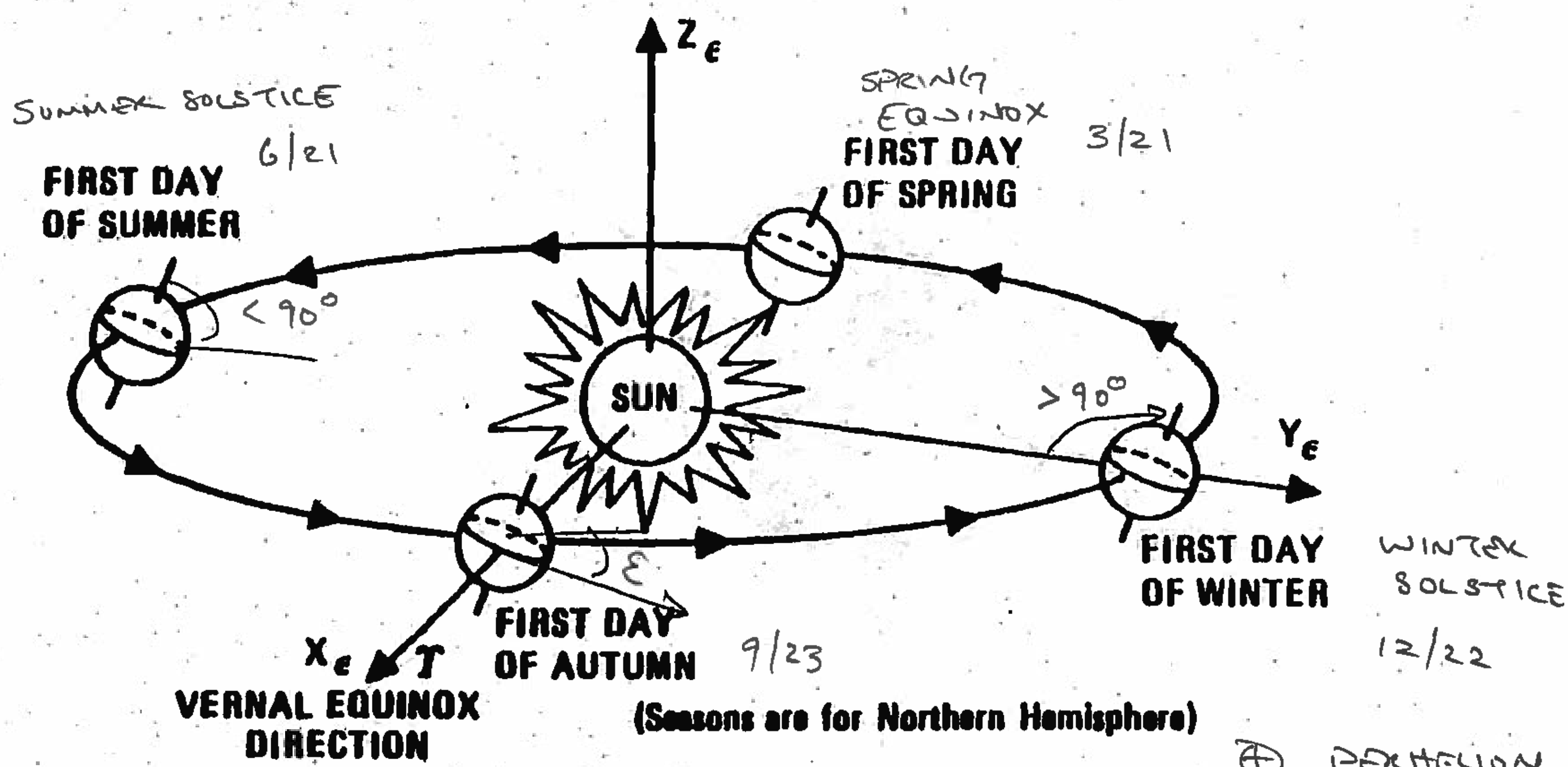
DUE TO EARTH'S PRECESSION THIS DIRECTION MOVES
IN CONSTELLATION PISCIS NOW – 4000 YRS SINCE IT'S BEEN
<u>IN ARIES</u> –



♈ – POINT WHERE
SUN CROSSES
EARTH'S EQUATOR MOVING
'NORTHWARD'

EARTH ORBIT NEARLY CIRCULAR: AXIS OF ROTATION WRT ECLIPTIC ≈ 23.5°

EQUINOX - LENGTH OF NIGHT/DAY EQUAL



⊕ PERIHELION
JAN 4

- REF. DIRECTION
- FIRST POINT OF ARIES → THIS MOVES
(4000 YRS AGO) IN PISCIS NOW

PRECESSION OF THE EQUINOXES

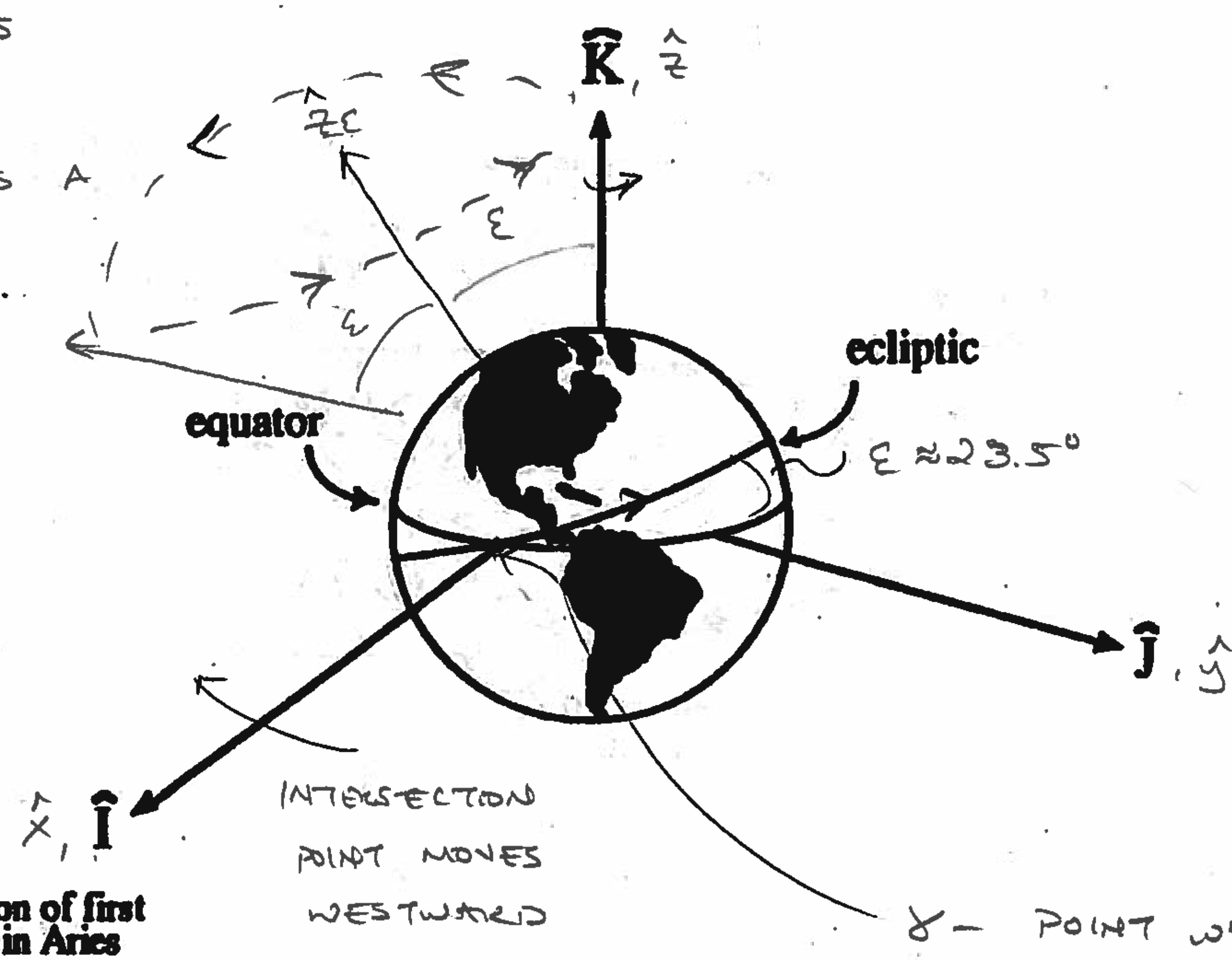
- CHANGE IN DIRECTION OF EARTH'S SPIN AXES
- CAUSED BY ☉, ☾
- PRECESSION - SAME AS A SPINNING TOP

~ 26000 YRS

γ MOVES $\dfrac{360^\circ}{26000 \text{ YRS}}$

$\approx \dfrac{4}{5} \dfrac{\text{ARC MIN}}{\text{YR}}$

$= 0.013^\circ/\text{YR}$



γ - POINT WHERE SUN CROSSES EARTH'S EQUATOR MOVING "NORTHWARD"

$1' = \frac{1}{60}$ OF 1° - ARCMIN

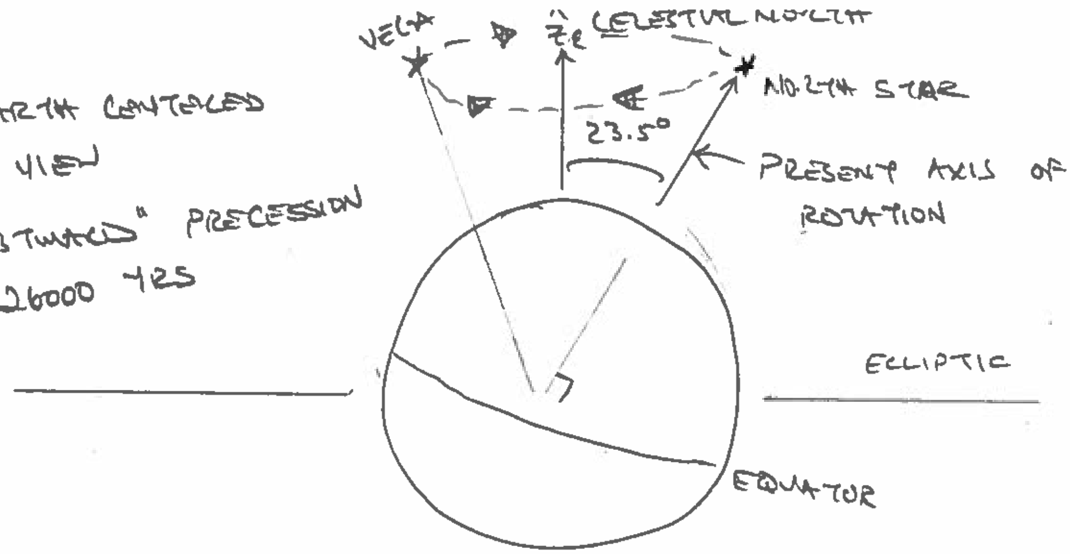
$1'' = \frac{1}{60}$ OF $1'$ - ARCSECOND

γ IS MOVING

1. NEED SPECIFIC EPOCH - J2000 1/1/2000 0:0 UTC
2. WE ASSUME $\hat{x}$ $\hat{y}$ IS FIXED

EARTH CENTERED VIEW

"WESTWARD" PRECESSION
~26000 YRS



NUTATION SHIFTS BTWN 18°–28°
↓
PERIOD OF ~18.6 YR

<u>PRECESSION OF THE EQUINOXES</u> – CHANGE IN THE DIRECTION OF EARTH'S SPIN AXIS

- CAUSED BY PERTURBATIONS ON EARTH'S ATTITUDE, ☉ + ☾
- PRECESSING MOTION – SAME AS A SPINNING TOP OR TORQUE FREE RIGID BODY
- KNOWN AS EARLY AS 2nd CENTURY BC TO HIPPARCHUS

γ MOVES THROUGH $\dfrac{360°}{26000 \text{ YRS}} = \dfrac{4}{5}$ ARC MIN PER YR

$= 0.013° / \text{YR}$

$1' = \frac{1}{60}$ OF $1°$ — ARCMIN

$1'' = \frac{1}{60}$ OF $1'$ — ARCSEC.

SINCE γ IS MOVING

1. WE MUST REFER TO A SPECIFIC EPOCH WHEN CATALOGING CELESTIAL OBJECTS — J2000 00:00 1/1/2000

2. WE WILL ASSUME γ IS FIXED – REASONABLE OVER SHORT INTERVALS.

GEOCENTRIC EQUATORIAL REF. SYSTEM – ECI

EARTH CENTERED INERTIAL

$\hat{i}, \hat{j}, \hat{k} = \hat{x}, \hat{y}, \hat{z}$ — EARTH EQUATORIAL PLANE

$\hat{i}, \hat{x}$ – POINTS TOWARDS γ

$\hat{k}, \hat{z}$ – ALIGNED WITH EARTH'S ROTATION AXIS

$\hat{y} = \hat{z} \times \hat{x}$

TO LOCATE S/C IN EARTH ORBIT

TRUE ANOMALY

LATER

1. LOCATE S/C IN ORBIT (θ, ν OR E, M) TRUE ANOMALY

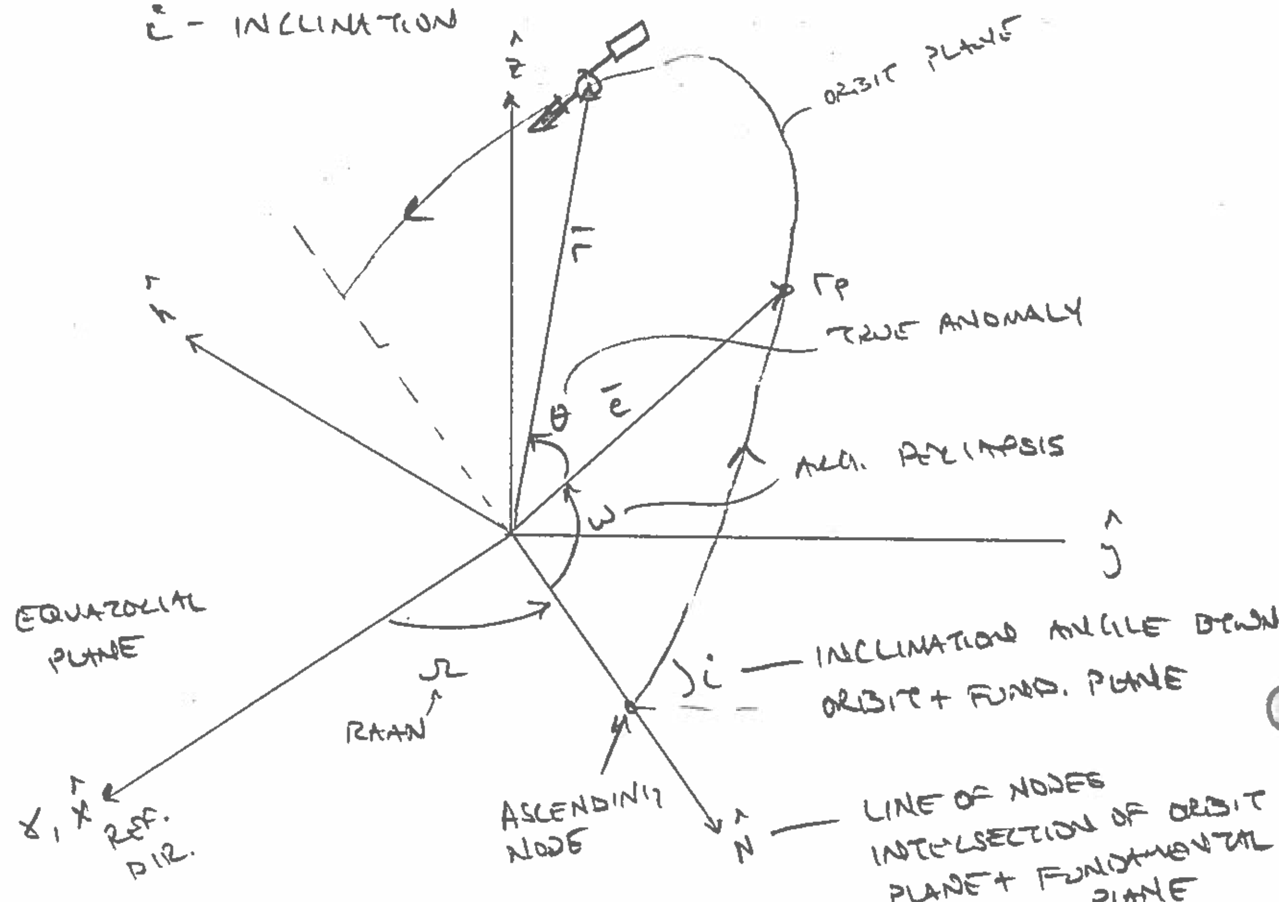
2. ORIENTATION OF ORBIT IN ORBIT PLANE (ω) ARG OF PERIAPSIS

3. SIZE | SHAPE OF ORBIT (a, e OR p)

4. ORIENTATION OF ORBIT PLANE WRT REF. SYSTEM (ECI) — (Ω, i)

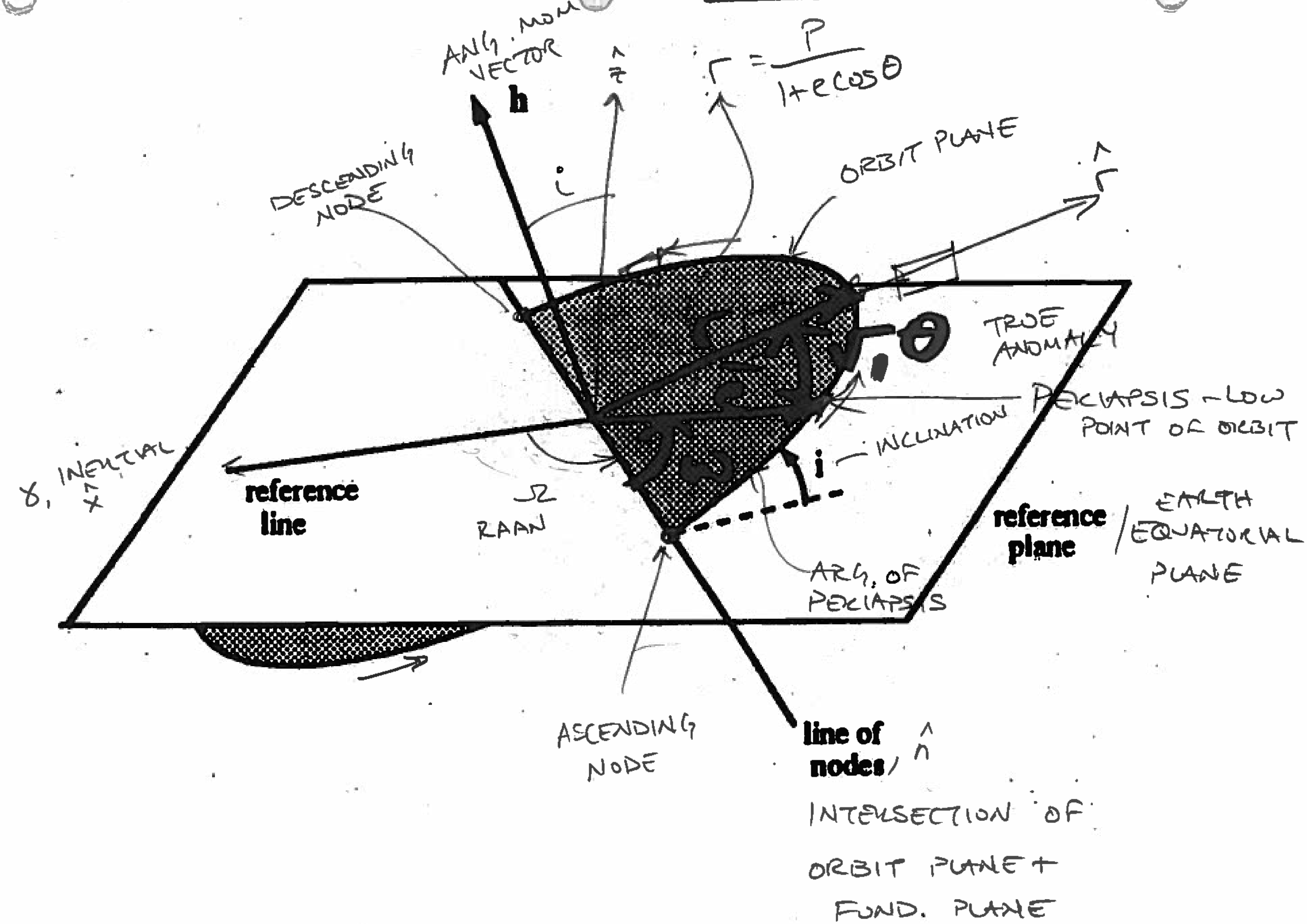
Ω. RIGHT ASCENSION OF ASCENDING NODE

i – INCLINATION

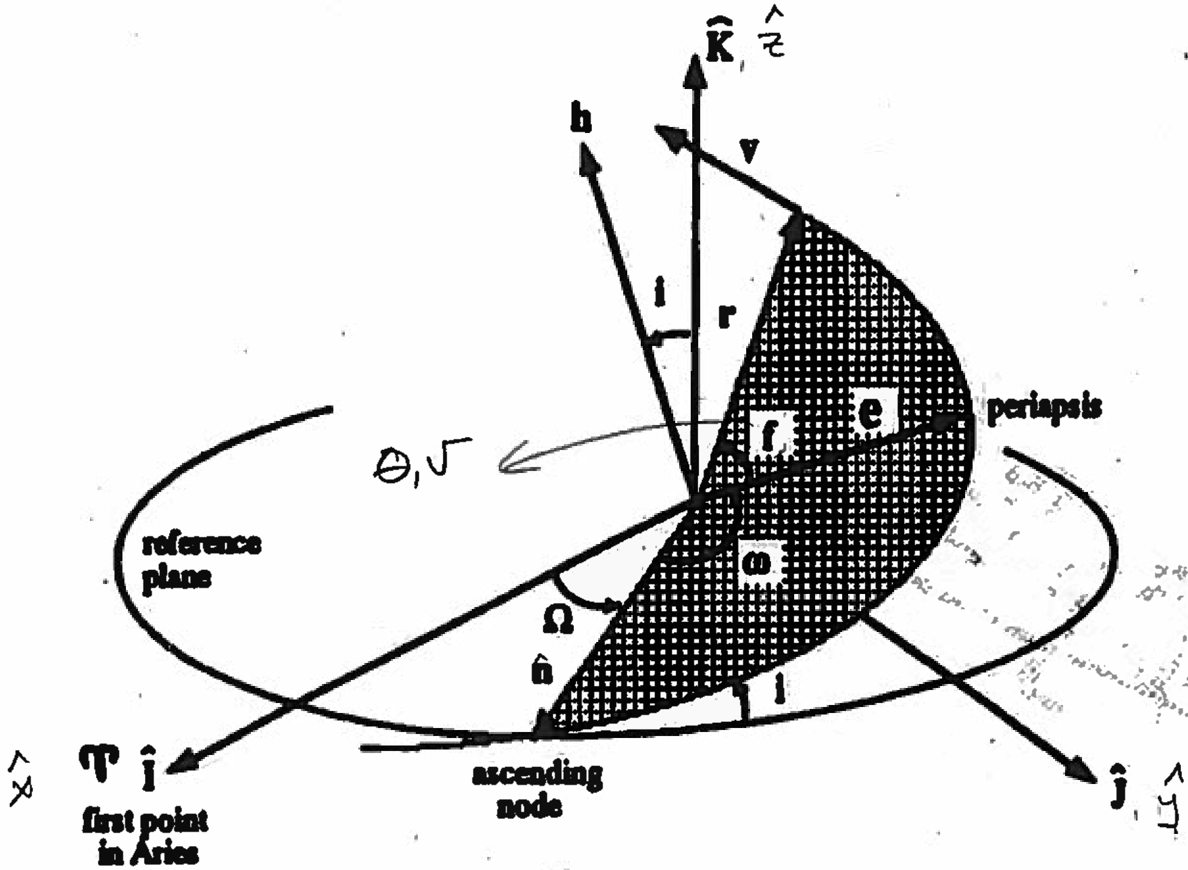


(3)

ECI


ANG. MOM VECTOR
h
$\hat{z}$
$r = \frac{p}{1+e\cos\theta}$
ORBIT PLANE
$\hat{r}$
DESCENDING NODE
i
θ
TRUE ANOMALY
PERIAPSIS – LOW POINT OF ORBIT
INCLINATION
i
γ, INERTIAL $\hat{x}$
reference line
Ω
RAAN
reference plane
EARTH EQUATORIAL PLANE
ARG. OF PERIAPSIS
ASCENDING NODE
line of nodes / $\hat{n}$
INTERSECTION OF ORBIT PLANE + FUND. PLANE

(4)



Ω : longitude of the ascending node

ω : argument of periapsis

$\tilde{\omega} = \Omega + \omega$: longitude of periapsis

DOG LEG ANGLES

f : true anomaly

$L = \tilde{\omega} + f$: true longitude

$L = \Omega + \omega + \theta$

HOMEWORK + PROJECT HELP

- MANY PROBLEMS ARE ASKING FOR THE SAME INFORMATION WITH DIFF. INPUTS

- AVOID REPEATING YOUR WORK - YOU SHOULD AUTOMATE REPETATIVE TASKS

- HW3 + PROJECT FORCE YOU TO WRITE A PROGRAM!

  ONCE WRITTEN YOU CAN CONTINUALLY USE IT.

HOMEWORK 2

- BOTH PROB 1 + PROB 3 UTILIZE THE RELATIVE N-BODY EQN.

$$\ddot{\bar{r}}_{qi} + \frac{G(M_q + m_i)}{r_{qi}^3}\bar{r}_{qi} = G\sum_{\substack{j=1 \\ j\neq i,q}}^{n}\left(\frac{\bar{r}_{ij}}{r_{ij}^3} - \frac{\bar{r}_{qj}}{r_{qj}^3}\right)$$

  THIS SHOULD BE A FCN $\longrightarrow$ SIMPLY DIFFERENT WAYS!

- PROBLEM 2 ASKED US TO COMPUTE SOME QUANTITIES

  HW3 ASK FOR THE SAME QUANTITIES

  ALL OF THESE CAN BE FCNS!

- YOUR HOMEWORK SOLUTION SHOULD SHOW YOUR WORK - ATTACH A COPY OF CODE SHOWING HOW YOU COMPUTED VALUES.

- MAKE SURE VECTORS ARE PROPERLY DEFINED

  DRAW A FIGURE!

HOMEWORK 3

- PROB 1, 3, 4, 6 - REQUIRE SOME THOUGHT
  ALGEBRA + SOME GEOMETRY
- PROB 2, 5, 7 - COMPUTE THE SAME VALUES FOR SEVERAL
  DIFF. CASES $\longrightarrow$ PROGRAM
- PROB 7 GIVES A TEST ANSWER TO USE IN VERIFYING YOUR
  CODE.

PROJECT . CONVERT RV 2 COE

- CONVERT FROM ECI TO COE
- MUST WRITE YOUR OWN PROGRAM
- ALGORITHM + DOCUMENTATION + TESTING
  - SOMEONE WITH ALGORITHM SHOULD BE ABLE WRITE
    YOUR PROGRAM IN ANY LANGUAGE
  - MORE THAN JUST EQUATIONS
  - INCLUDE ERROR CHECKS | UNITS + DESCRIPTIONS
  - MUST BE TYPED

CLASSICAL ORBITAL ELEMENTS

- NEED TO GAIN THE ABILITY TO VISUALIZE ORBITS
- DRAW A PICTURE

EXAMPLE 1

$p = 2R_\oplus$

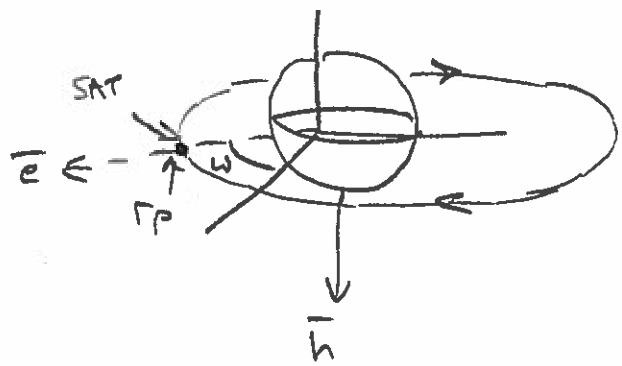
$e = 0.2$

$i = 180°$ – RETROGRADE EQ.

Ω = UND.

$L/\omega = 45°$ – LOCATION OF PERIAPSIS

$\nu = 0°$



EXAMPLE 2

$p = 3R_\oplus$

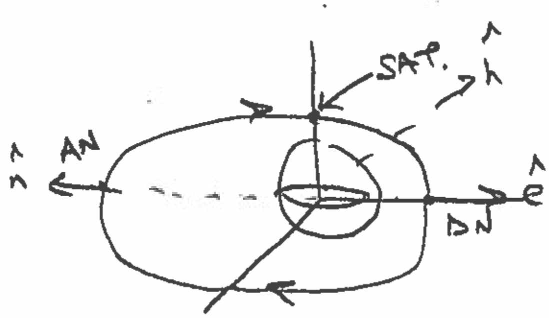
$e = 0.2$

$i = 90°$ ← POLAR

$\Omega = 270°$

$\omega = 180°$

$\nu = 270°$



CLASSICAL ORBITAL ELEMENTS

a - SEMI-MAJOR AXIS - SIZE

e - ECCENTRICITY - SHAPE

} p - SEMI-PARAMETER $p = a(1-e^2)$

i - INCLINATION ANGLE BTWN ORBIT PLANE + FUNDAMENTAL PLANE

Ω - RIGHT ASCENSION OF ASCENDING NODE "LONGITUDE" - ANGLE BTWN $\hat{x}$ AND POINT WHERE SATELLITE CROSSES F. PLANE CCW ALIGNED WITH $\hat{z}$

ω - ARGUMENT OF PERIAPSIS - ANGLE BTWN PERIAPSIS + ASCENDING NODE - IN ORBIT PLANE IN DIRECTION OF MOTION

θ, ν - TRUE ANOMALY - ANGLE BTWN PERIAPSIS + SAT IN ORBIT PLANE - MEASURED IN DIRECTION OF MOTION

OTHER ANGLES FOR SPECIAL CASES

$\tilde{\omega} = \Omega + \omega$ - LONGITUDE OF PERIAPSIS

$L = \tilde{\omega} + \nu$ - TRUE LONGITUDE

} DOG LEG ANGLES

DIRECT ORBIT - "EASTERLY" $0° < i \leq 90°$

RETROGRADE - "WESTERLY" $90° < i \leq 180°$

CURTIS - CH 4, BMW 2.1-2.6

EXAMPLE CONVERT $\bar{R}, \bar{V} \rightarrow$ COE

GIVEN

$$\bar{r} = 1.6772 R_\oplus \hat{x} - 1.6772 R_\oplus \hat{y} + 2.3719 R_\oplus \hat{z}$$
$$\bar{v} = 3.1574 \hat{x} + 2.4987 \hat{y} + 0.4658 \hat{z} \quad \text{km/sec}$$
} ECI

FIND: $a, e, i, \Omega, \omega, \theta$

SOLUTION: ALGORITHM

1. FIND $\bar{h}, \bar{e}, \bar{n}$

$$\bar{h} = \bar{r} \times \bar{v} \Rightarrow \hat{h} \approx -0.5\hat{x} + 0.5\hat{y} + 0.7071\hat{z}$$

$$\bar{n} = \hat{z} \times \hat{h} \Rightarrow \hat{n} \approx -0.707\hat{x} - 0.707\hat{y}$$

$$\bar{e} = \frac{1}{\mu}\left[\left(v^2 - \frac{\mu}{r}\right)\bar{r} - (\bar{r}\cdot\bar{v})\bar{v}\right] \Rightarrow \hat{e} \approx -0.8\hat{x} - 0.14\hat{y} - 0.5\hat{z}$$

2. $p = h^2/\mu \qquad p = a(1-e^2)$

$e = |\bar{e}| \qquad \mathcal{E} = \frac{-\mu}{2a} = \frac{v^2}{2} - \frac{\mu}{r}$

$a = 3R_\oplus$
$e = 0.2$
} CHECK r_p, r_a FOR COLLISIONS

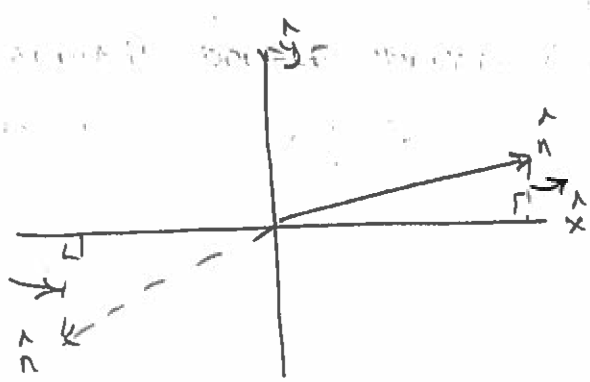
3. INCLINATION - ANGLE BTWN $\hat{z}$ + $\hat{h}$

$\cos i = \hat{z}\cdot\hat{h} \qquad 0 \le i \le 180 \qquad i = 45^\circ$ QUADRANT CHECK

4. RAAN - ANGLE BTWN $\hat{x}$ AND ASCENDING NODE

$\cos\Omega = \hat{x}\cdot\hat{n} \qquad 0 \le \Omega \le 360 \qquad \Omega = 225^\circ$

MUST CHECK THE QUADRANT!

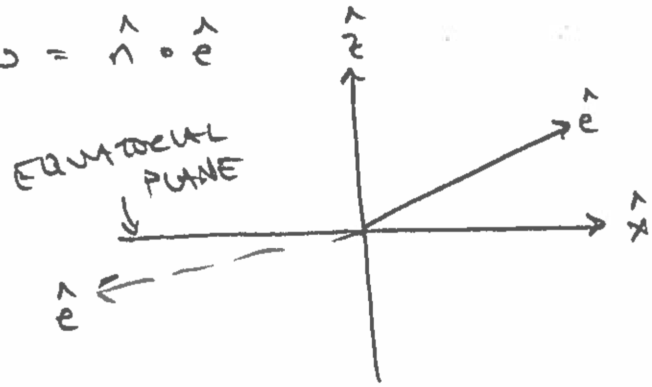


IF $\hat{n}\cdot\hat{y} > 0$
$0 < \Omega < 180$
IF $\hat{n}\cdot\hat{y} < 0$
$180 < \Omega < 360$

5. ARGUMENT OF PERIGEE – ANGLE FROM ASCENDING NODE TO PERIAPSIS $0^\circ < \omega < 360^\circ$

$\omega = -45^\circ$
$= 315^\circ$

$\cos \omega = \hat{n} \cdot \hat{e}$



IF $\hat{e} \cdot \hat{z} > 0$

$0 \leq \omega \leq 180$

IF $\hat{e} \cdot \hat{z} < 0$

$180 < \omega \leq 360$

6. TRUE ANOMALY – POSITION OF SATELLITE RELATIVE TO PERIAPSIS $0 \leq \nu \leq 360^\circ$

$\nu = 135^\circ$

$\cos \nu = \hat{e} \cdot \hat{r}$

$$\left.\begin{array}{lll} \text{IF} & \hat{r} \cdot \hat{v} < 0 & 180 \leq \nu \leq 360 \\ \text{IF} & \hat{r} \cdot \hat{v} > 0 & 0 \leq \nu \leq 180^\circ \end{array}\right\} \text{FLIGHT PATH ANGLE}$$

SPECIAL CASES

ELLIPTICAL EQUATORIAL – NO ASCENDING NODE Ω UNDEF

USE $\tilde{\omega} = \Omega + \omega$ $\cos \tilde{\omega} = \hat{x} \cdot \hat{e}$

CIRCULAR INCLINED – NO PERIAPSIS ω, ν UNDEFINED

USE $u = \omega + \nu$ ARGUMENT OF LATITUDE $\cos u = \hat{n} \cdot \hat{r}$

CIRCULAR EQUATORIAL – Ω, ω, ν UNDEF.

USE TRUE LONGITUDE $L = \tilde{\omega} + \nu$ $\cos L = \hat{x} \cdot \hat{r}$

EXAMPLE RV TO COE

POSITION + VELOCITY IN ECI

$\bar{r} = 6524.834\,\hat{i} + 6862.875\,\hat{j} + 6448.296\,\hat{k}$ km

$\bar{v} = 4.901327\,\hat{i} + 5.533756\,\hat{j} - 1.976341\,\hat{k}$ km/sec

1. FIND ANGULAR MOMENTUM VECTOR

$\hat{h} = \hat{r} \times \hat{v} = -0.74\,\hat{i} + 0.669\,\hat{j} + 0.037\,\hat{k}$

2. FIND LINES OF NODES + ECCENTRICITY

$\hat{n} = \hat{k} \times \hat{h} = -.67\,\hat{i} - 0.74\,\hat{j} + 0\,\hat{k}$

$\hat{e} = \frac{1}{\mu}\left[\left(v^2 - \frac{\mu}{r}\right)\bar{r} - (\bar{r}\cdot\bar{v})\bar{v}\right] = -0.37\,\hat{i} - 0.46\,\hat{j} + 0.82\,\hat{k}$

$e = 0.832853$

$\varepsilon = \frac{v^2}{2} - \frac{\mu}{r} =$

3. USE ELLIPTICAL RELATION FOR $a = \frac{-\mu}{2\varepsilon} = 36127.343$ km

$p = \frac{h^2}{\mu} = 11067.790$ km

4. INCLINATION $\cos i = \hat{h}\cdot\hat{k}$ → 87.870°

5. RAAN $\cos\Omega = \hat{i}\cdot\hat{n}$ IF $\hat{n}\cdot\hat{j} < 0$ $\Omega = 360 - \Omega$

$\Omega = 227.89$

6. ARGP $\cos\omega = \hat{n}\cdot\hat{e}$ IF $\hat{e}\cdot\hat{k} < 0$ $\omega = 360^\circ - \omega$

$\omega = 53.38^\circ$

7. ν $\cos\nu = \hat{e}\cdot\hat{r}$ IF $\hat{r}\cdot\hat{v} < 0$ $\nu = 360^\circ - \nu$

$\nu = 92.335^\circ$

TRANSFORM BTWN PQW → ECI

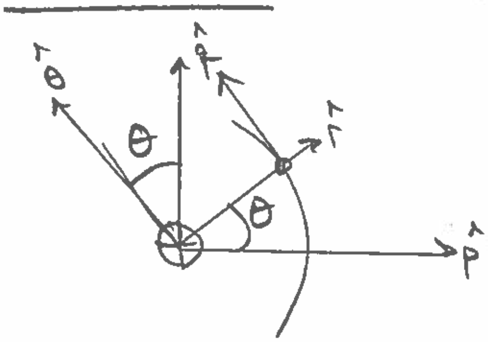
- CONCEPTS COME FROM COORDINATE TRANSFORMATIONS
  - LOOK IN ANY DYNAMICS OR MATH TEXTBOOK
- TYPICALLY REQUIRE A TRANSLATION + ROTATION
- KEY IDEA: A VECTOR CAN BE REPRESENTED IN ANY COORD. SYSTEM — "A VECTOR IS A VECTOR"

  MAGNITUDE + DIRECTION REMAIN UNCHANGED ONLY THE COMPONENTS | REPRESENTATION CHANGES

DEAL WITH ROTATIONS NOW

TWO BASIC IDEAS - BREAK ROTATION INTO COMPONENTS
- LOOK AT UNIT VECTORS

LVLH → PQW



$$\hat{r} = \cos\theta\,\hat{p} + \sin\theta\,\hat{q} + 0\,\hat{w}$$

$$\hat{\theta} = -\sin\theta\,\hat{p} + \cos\theta\,\hat{q} + 0\,\hat{w}$$

$$\hat{h} = \hat{w}$$

$$\begin{array}{cccccc} & & \hat{r} & \hat{\theta} & \hat{h} & \\ \begin{bmatrix}\hat{p}\\ \hat{q}\\ \hat{w}\end{bmatrix} & = & \multicolumn{3}{c}{\begin{bmatrix}\cos\theta & -\sin\theta & 0\\ \sin\theta & \cos\theta & 0\\ 0 & 0 & 1\end{bmatrix}} & \begin{bmatrix}\hat{r}\\ \hat{\theta}\\ \hat{h}\end{bmatrix}\end{array}$$

COLUMNS ARE $\hat{r}\,\hat{\theta}, \hat{h}$ REPRESENTED IN $\hat{P}\hat{Q}\hat{W}$ FRAME

WE CAN USE A SIMILAR PROCESS TO TRANSFORM BTWN PQW + ECI

RECALL THE PQW REF. FRAME

$\hat{p}$ - POINTS IN DIRECTION OF PERIAPSIS $\longrightarrow$ ALONG $\bar{e}$

$\hat{q}$ - ALONG SEMI-LATUS RECTUM $\hat{q} = \hat{\omega} \times \hat{p}$

$\hat{w}$ - ALONG ANG. MOM. VECTOR $\hat{\omega} = \hat{h} = \bar{r} \times \bar{v}$

GIVEN $\bar{r}, \bar{v}$ IN THE ECI FRAME

$$\hat{p} = \hat{e} = \frac{\left(v^2 - \frac{\mu}{r}\right)\bar{r} - (\bar{r}\cdot\bar{v})\bar{v}}{\mu} \cdot \frac{1}{e}$$

$$\hat{q} = \hat{\omega} \times \hat{p}$$

$$\hat{\omega} = \hat{r} \times \hat{v}$$

$$\begin{bmatrix} \hat{I} \\ \hat{J} \\ \hat{K} \end{bmatrix} = \begin{bmatrix} \hat{p} & \hat{q} & \hat{w} \end{bmatrix} \begin{bmatrix} \hat{p} \\ \hat{q} \\ \hat{w} \end{bmatrix}$$

OR CAN BE DEFINED USING OUR COES

$\hat{P}\hat{Q}\hat{W}$ TO $\hat{I}\hat{J}\hat{K}$

$$R_{\substack{PQW \\ 2\,ECI}} = \begin{bmatrix} \cos\Omega\cos\omega - \sin\Omega\sin\omega\cos i & -\cos\Omega\sin\omega - \sin\Omega\cos\omega\cos i & \sin\Omega\sin i \\ \sin\Omega\cos\omega + \cos\Omega\sin\omega\cos i & -\sin\Omega\sin\omega + \cos\Omega\cos\omega\cos i & -\cos\Omega\sin i \\ \sin\omega\sin i & \cos\omega\sin i & \cos i \end{bmatrix}$$

REVIEW

$$\bar{r}_{pqw} = R_{\substack{LVLH2 \\ PQW}}\, \bar{r}_{LVLH} \qquad \bar{r}_{ECI} = R_{\substack{PQW \\ 2ECI}}\, \bar{r}_{PQW}$$

$$\bar{r}_{LVLH} = R_{\substack{LVLH2 \\ PQW}}^{T}\, \bar{r}_{PQW} \qquad \bar{r}_{PQW} = R_{\substack{PQW \\ 2ECI}}^{T}\, \bar{r}_{ECI}$$

CONVERTING COE → R, V

- BASIC IDEA IS TO DEFINE POSITION IN PERIFOCAL FRAME THEN ROTATE TO GEOCENTRIC EQUATORIAL

1. - FIRST DEFINE POSITION AND VELOCITY IN THE LVLH FRAME

$$\bar{r}_{LVLH} = \frac{p}{1+e\cos\nu}\hat{r} + 0\hat{\theta} + 0\hat{h} = r\hat{r}$$

$$\bar{v}_{LVLH} = \frac{\mu}{h} e\sin\theta\,\hat{r} + \frac{\mu}{h}(1+e\cos\theta)\hat{\theta} + 0\hat{h}$$

2. CONVERT TO PERIFOCAL FRAME USING TRUE ANOMALY θ, ν

SKIPPING SOME MATH - PROVE FOR YOURSELF

$$R_{\substack{LVLH2\\PQW}} = \begin{bmatrix} c\nu & -s\nu & 0 \\ s\nu & c\nu & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad \bar{r}_{PQW} = R_{\substack{LVLH2\\PQW}}\,\bar{r}_{LVLH}$$

$$\bar{r}_{PQW} = r\cos\nu\,\hat{p} + r\sin\nu\,\hat{q} + 0\hat{w}$$

$$\bar{v}_{PQW} = -\frac{\mu}{h}\sin\nu\,\hat{p} + \frac{\mu}{h}(e+\cos\theta)\hat{q} + 0\hat{w}$$

3. ROTATE TO ECI

$$\bar{r}_{ECI} = R_{\substack{PQW2\\ECI}}\,\bar{r}_{PQW}$$

$$\bar{v}_{ECI} = R_{\substack{PQW2\\ECI}}\,\bar{v}_{PQW}$$

PROJECT – RV2COE

- WRITE PROGRAM TO CONVERT RV → COES
- GOAL IS STRUCTURED PROGRAMMING
- 3 MAIN COMPONENTS
  - ALGORITHMS – DESCRIBE IN WORDS YOUR CODE
  - DOCUMENTED + TESTED CODE
  - MATCH GIVEN TEST CASES
  - RANDOM SOLUTION TO GIVEN LIST.
- DUE DATES

  ALGORITHM –

  CODE + SOLUTION –

ALGORITHM

- USE YOUR WORDS TO DESCRIBE WHAT THE CODE WILL DO
- SHOW EQUATIONS – TYPED IN AN EQUATION EDITOR
- SOMEONE WITH NO ASTRODYNAMICS BACKGROUND SHOULD BE ABLE TO USE IT !! ANY PROGRAMMING LANGUAGE
- DESCRIBE INPUTS / OUTPUTS TO FCNS.
- SHOW EXAMPLE.

PYTHON SKILLS

- AVOID REPEATING YOUR CODE – USE FUNCTIONS
- ALLOWS FOR EASIER CODE REUSE
- SCRIPTS

  FILE WITH SERIES OF PYTHON COMMANDS

  NO DIFFERENT THAN TYPING SAME COMMANDS
  DIRECTLY INTO INTERPRETER

FUNCTION

```
def name ():
    return 2
```

- GROUPING OF STATEMENTS
- TAKES 1/MANY INPUTS
- RETURNS OUTPUTS
- TYPICALLY FOCUSED ON A SPECIFIC TASK | OPERATION
- LIMITED IN SCOPE – ALLOWS FOR MODULARIZATION !!

MODULE

- LOGICAL GROUPING OF MANY FUNCTIONS
- ANY PYTHON FILE IS A MODULE
- ACCESS DATA USING IMPORT

PACKAGE

- LOGICAL MAPPING OF MANY MODULES
- CREATE BY PLACING EMPTY __init__.py IN DIRECTORY
- ACCESS USING IMPORT !

DOCUMENTATION

- CODE REQUIRES DOCUMENTATION
- FOR YOURSELF + OTHERS
- MINIMUM IS HOW TO USE THE CODE
- EXAMPLES + REFERENCES ALSO HELPFUL.
- YOU MUST DOCUMENT → GRADED ON THIS
- FOLLOW EXAMPLE

TESTING

- ALL OF YOUR CODE MUST BE TESTED
- SINCE IT'S SO VITAL → AUTOMATIC + FREQUENT TESTING IS THE HABIT YOU NEED TO DEVELOP
- ENSURES EACH FUNCTION WORKING PROPERLY BEFORE MOVING FORWARD
- WE'LL USE THE PYTEST FRAMEWORK
- ONE APPROACH IS TO CREATE TESTS FIRST THEN WRITE A FUNCTION TO PASS YOUR TESTS