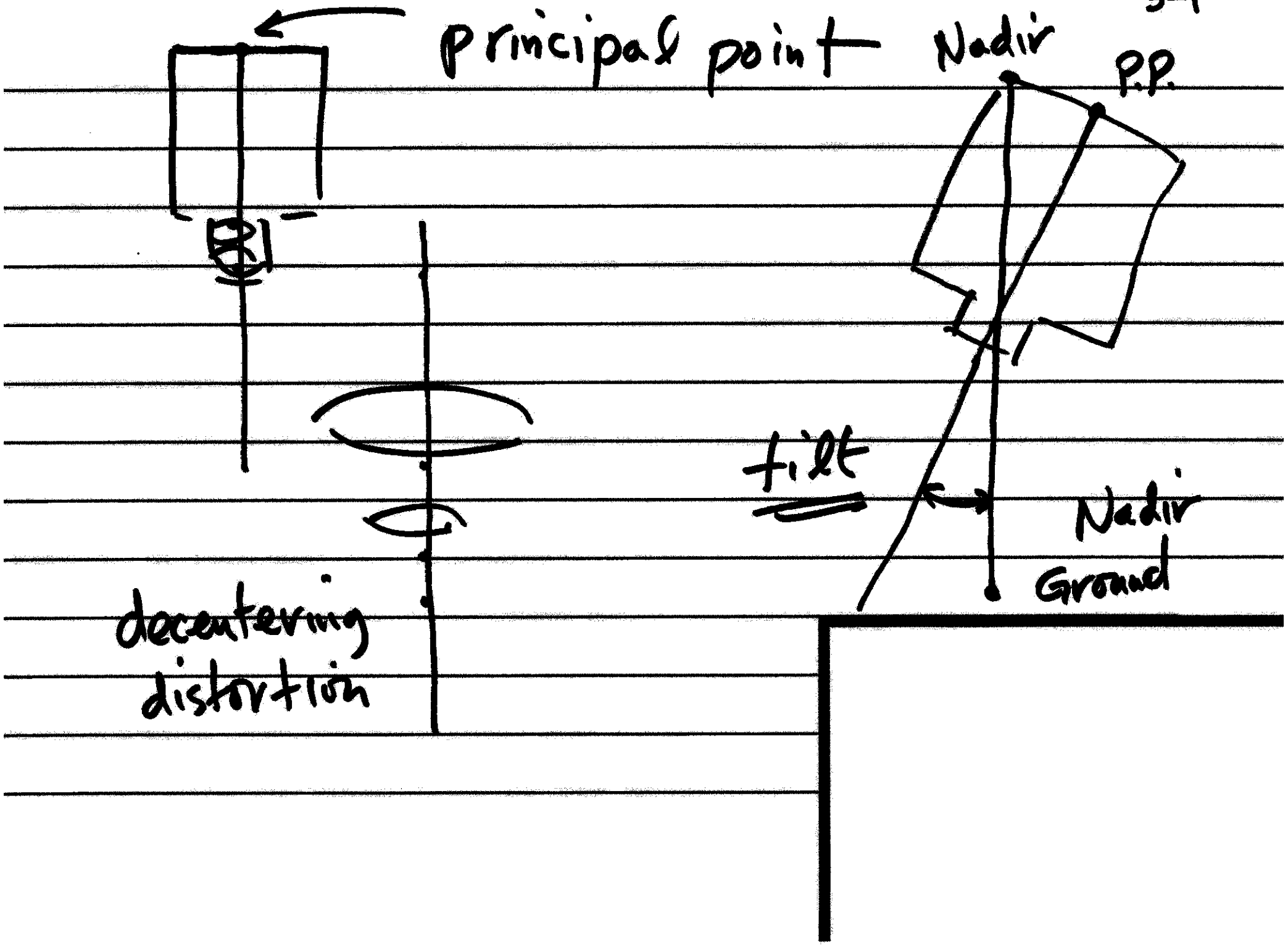
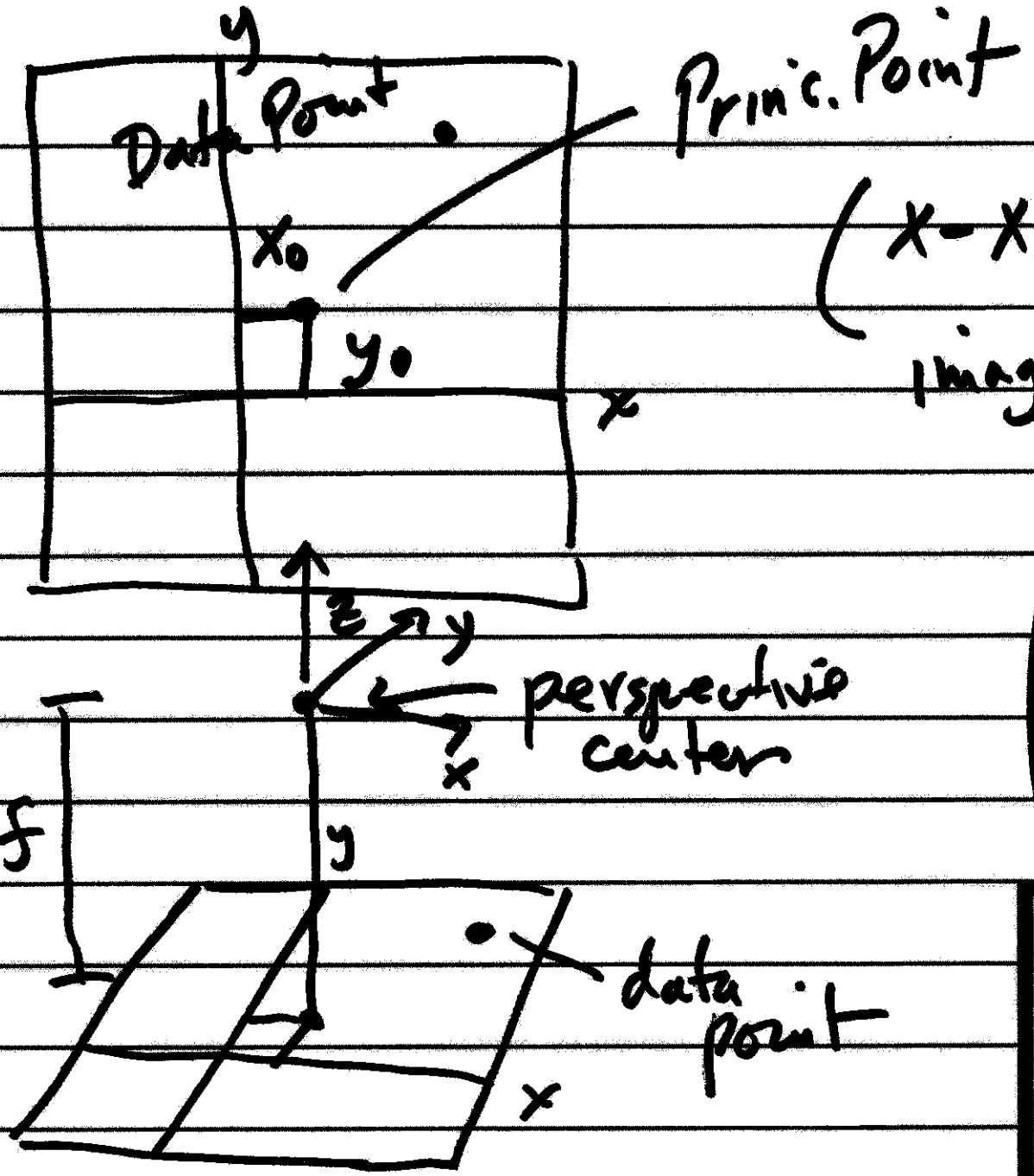

principal point
Nadir
P.P.
tilt
Nadir
Ground
decentering
distortion



$(x - x_0, y - y_0)$ 2D

image coordinate

$$\begin{pmatrix} x - x_0 \\ y - y_0 \\ -f \end{pmatrix}$$ 3D

sensor coord.

$$\begin{pmatrix} x \\ y \end{pmatrix} : \begin{pmatrix} x' \\ y' \\ w \end{pmatrix} \qquad x = \frac{x'}{w} \qquad y = \frac{y'}{w}$$

Homogeneous Coordinates

2D

$$\begin{pmatrix} x' \\ y' \\ z' \\ w \end{pmatrix}_T = \begin{bmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} x' \\ y' \\ z' \\ w \end{pmatrix}$$

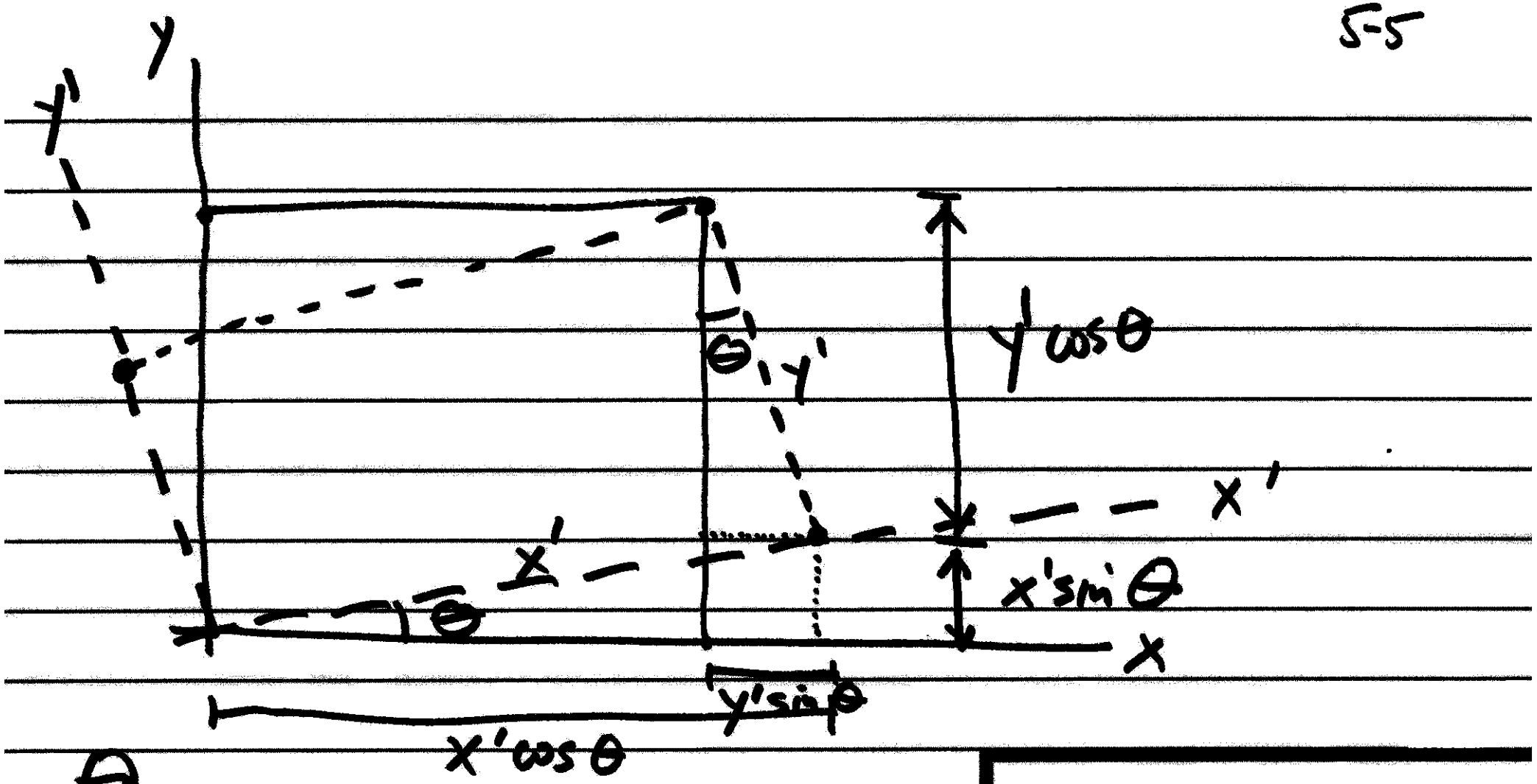
$$x'_T = x' + t_x w$$

$$y'_T = y' + t_y w$$

$$\vdots$$

$$\begin{pmatrix} x' \\ y' \\ z' \\ w \end{pmatrix}_{Rot} = \begin{bmatrix} & M_{3\times3} & & 0 \\ & & & 0 \\ & & & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} x' \\ y' \\ z' \\ w \end{pmatrix}$$

$$\begin{pmatrix} x' \\ y' \\ z' \\ w \end{pmatrix}_{Scaled} = \begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} x' \\ y' \\ z' \\ w \end{pmatrix}$$



$$X = x' \cos\theta - y' \sin\theta$$

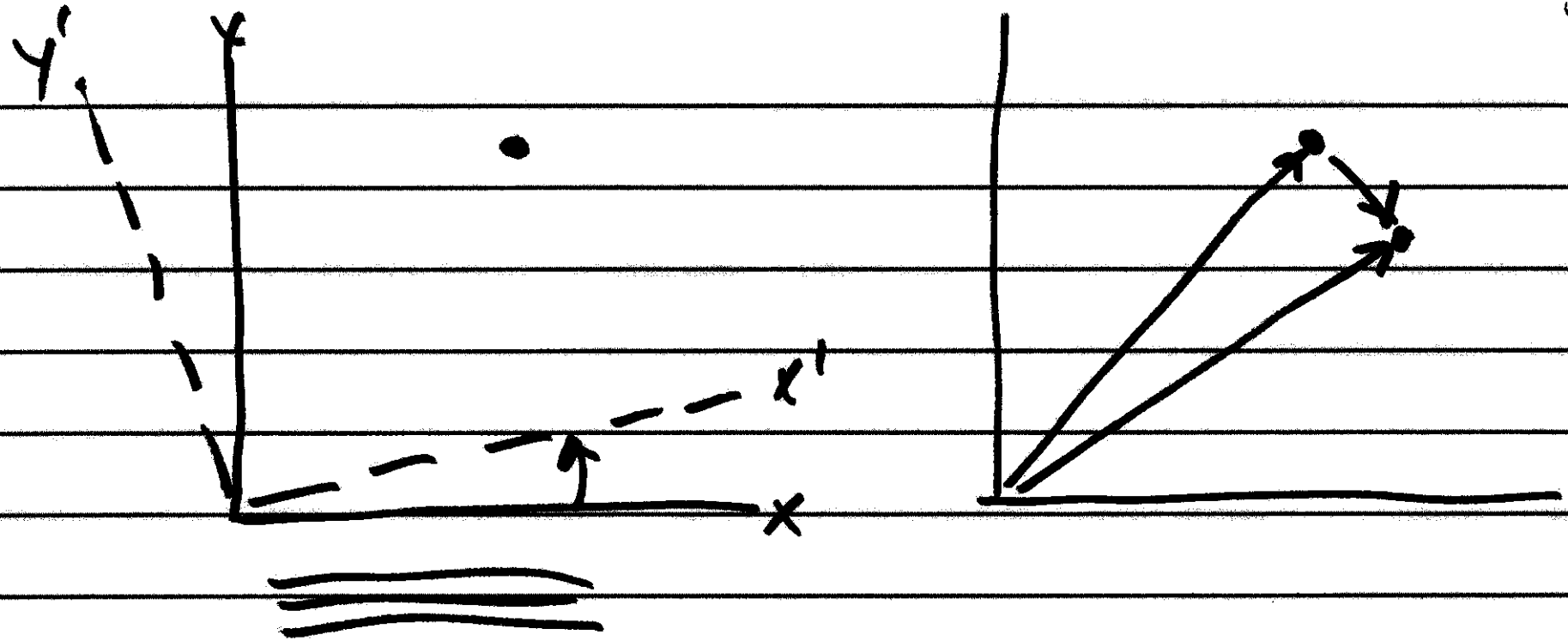
$$Y = x' \sin\theta + y' \cos\theta$$

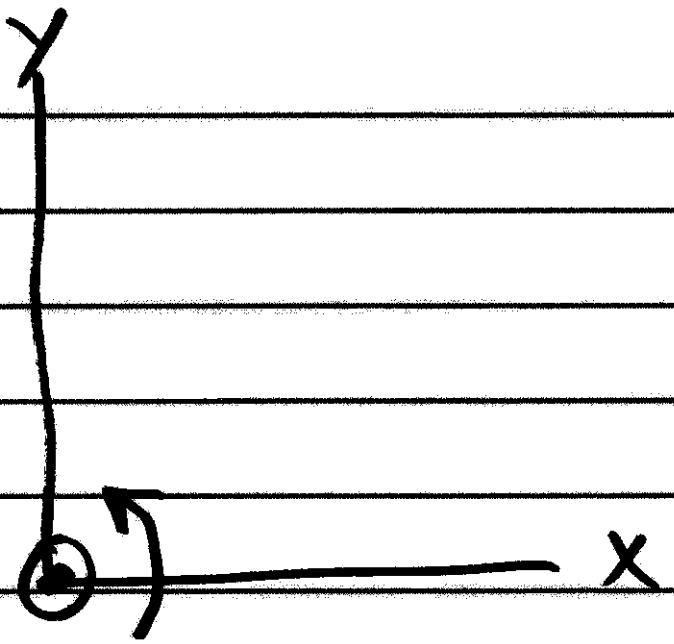
$$\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} x' \\ y' \end{pmatrix}$$

matrix orthogonal

inverse = transpose

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} X \\ Y \end{pmatrix}$$

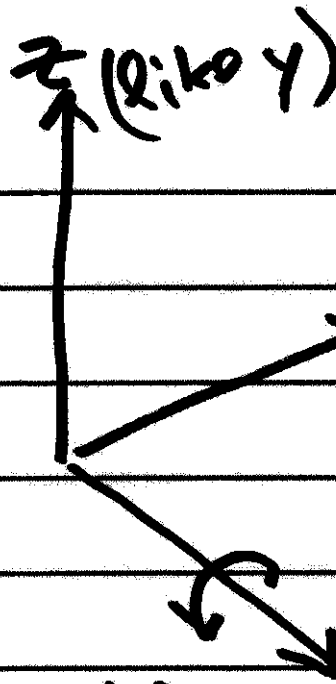

y'
y
x'
x



K : Kappa

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \underbrace{\begin{pmatrix} \cos K & \sin K & 0 \\ -\sin K & \cos K & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{M_K} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

R_3

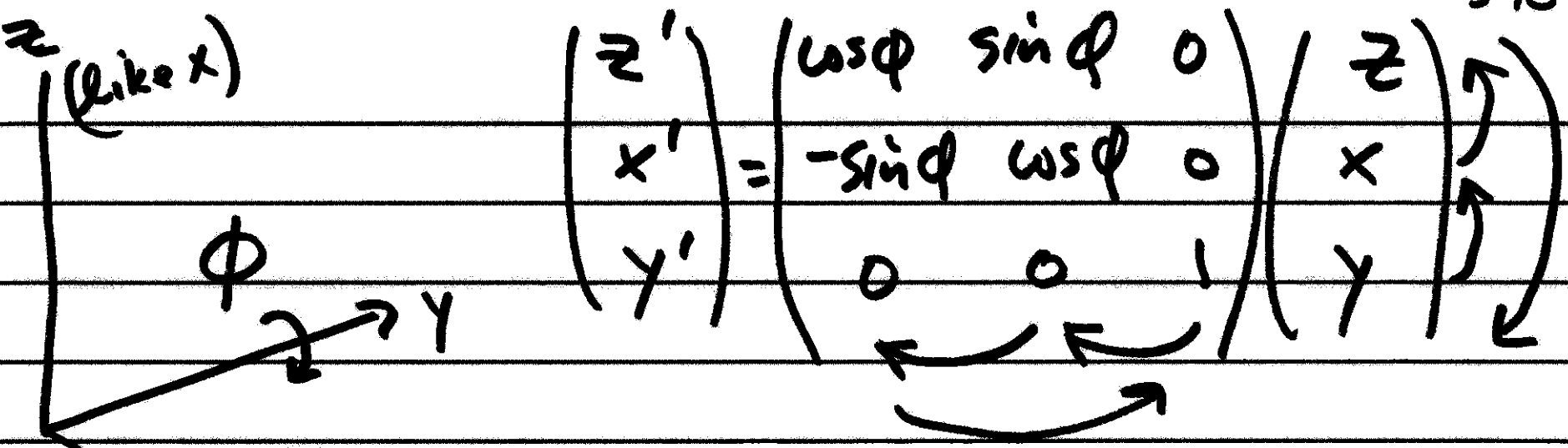


$$\begin{pmatrix} y' \\ z' \\ x' \end{pmatrix} = \begin{pmatrix} \cos\omega & \sin\omega & 0 \\ -\sin\omega & \cos\omega & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} y \\ z \\ x \end{pmatrix}$$

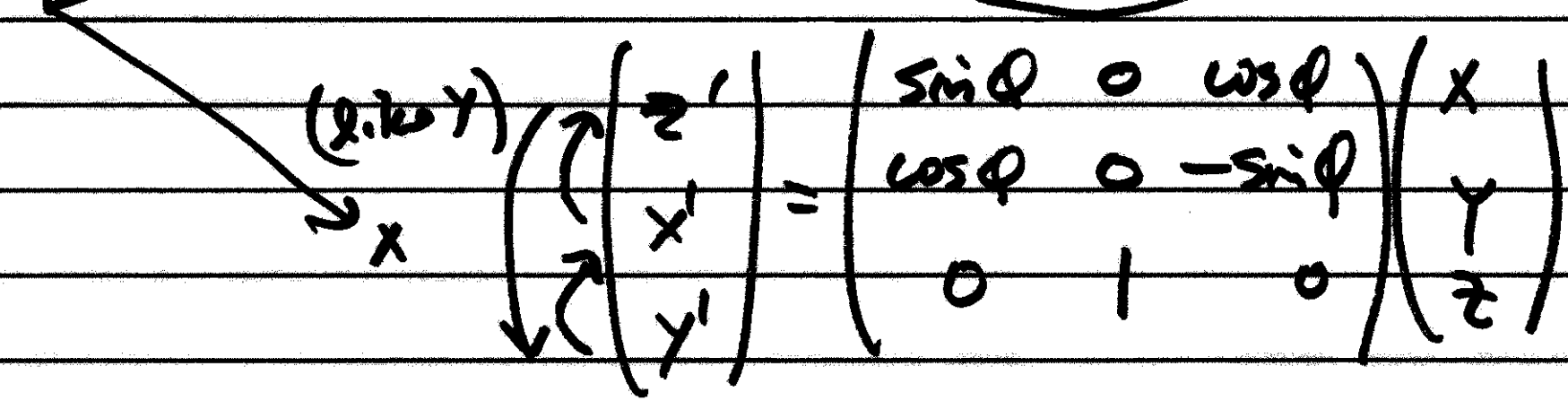
$$\begin{pmatrix} y' \\ z' \\ x' \end{pmatrix} = \begin{pmatrix} 0 & \cos\omega & \sin\omega \\ 0 & -\sin\omega & \cos\omega \\ 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & \sin\omega \\ 0 & -\sin\omega & \cos\omega \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

M_x, R_1



$$\begin{pmatrix} z' \\ x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} z \\ x \\ y \end{pmatrix}$$



$$\begin{pmatrix} z' \\ x' \\ y' \end{pmatrix} = \begin{pmatrix} \sin\phi & 0 & \cos\phi \\ \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \underbrace{\begin{pmatrix} \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \\ \sin\phi & 0 & \cos\phi \end{pmatrix}}_{M_\phi,\ R_2} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

$$M = \begin{bmatrix} \cos\phi\cos\kappa & \cos\omega\sin\kappa + \sin\omega\sin\phi\cos\kappa & \sin\omega\sin\kappa - \cos\omega\sin\phi\cos\kappa \\ -\cos\phi\sin\kappa & \cos\omega\cos\kappa - \sin\omega\sin\phi\sin\kappa & \sin\omega\cos\kappa + \cos\omega\sin\phi\sin\kappa \\ \sin\phi & -\sin\omega\cos\phi & \cos\omega\cos\phi \end{bmatrix}$$

3×3

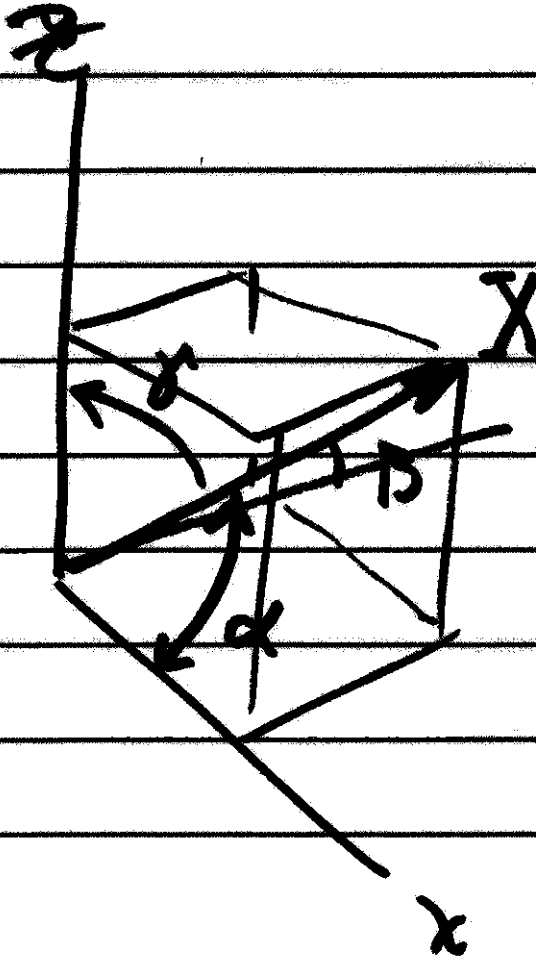
$$M = M_\kappa M_\phi M_\omega$$

$$M = M_K M_\varphi M_\omega \leftarrow$$

$$M = M_\varphi M_\omega M_K$$

$$M = M_K M_\omega M_K$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = M \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}, \quad \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad M = \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix}$$



$$\begin{pmatrix} m_{11} \\ m_{21} \\ m_{31} \end{pmatrix} = M \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \qquad \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \qquad \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} \cos\alpha \\ \cos\beta \\ \cos\gamma \end{pmatrix}$$

$$M = \begin{bmatrix} \cos xX & \cos xY & \cos xZ \\ \cos yX & \cos yY & \cos yZ \\ \cos zX & \cos zY & \cos zZ \end{bmatrix}$$

direction cosines

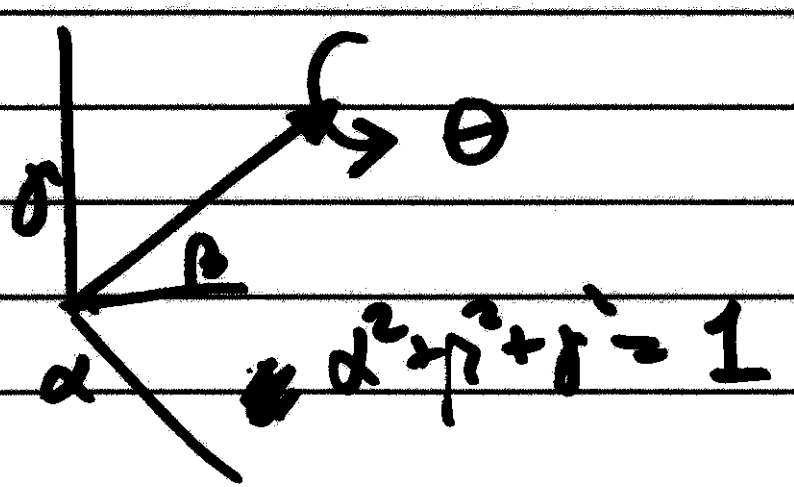
algebraic parameters

$$M = \begin{bmatrix} d^2+a^2-b^2-c^2 & 2(ab+cd) & 2(ac-bd) \\ 2(ab-cd) & d^2-a^2+b^2-c^2 & 2(bc+ad) \\ 2(ac+bd) & 2(bc-ad) & d^2-a^2-b^2+c^2 \end{bmatrix}$$

$$a^2+b^2+c^2+d^2 = 1$$

Rotation @ Directed Line

$$M = \begin{bmatrix} \alpha^2(1-\cos\theta)+\cos\theta & \alpha\beta(1-\cos\theta)-\gamma\sin\theta & \alpha\gamma(1-\cos\theta)+\beta\sin\theta \\ \alpha\beta(1-\cos\theta)+\gamma\sin\theta & \beta^2(1-\cos\theta)+\cos\theta & \beta\gamma(1-\cos\theta)-\alpha\sin\theta \\ \alpha\gamma(1-\cos\theta)-\beta\sin\theta & \beta\gamma(1-\cos\theta)+\alpha\sin\theta & \gamma^2(1-\cos\theta)+\cos\theta \end{bmatrix}$$



* $\alpha^2+\beta^2+\gamma^2 = 1$