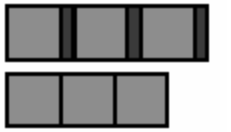
Error Accumulation

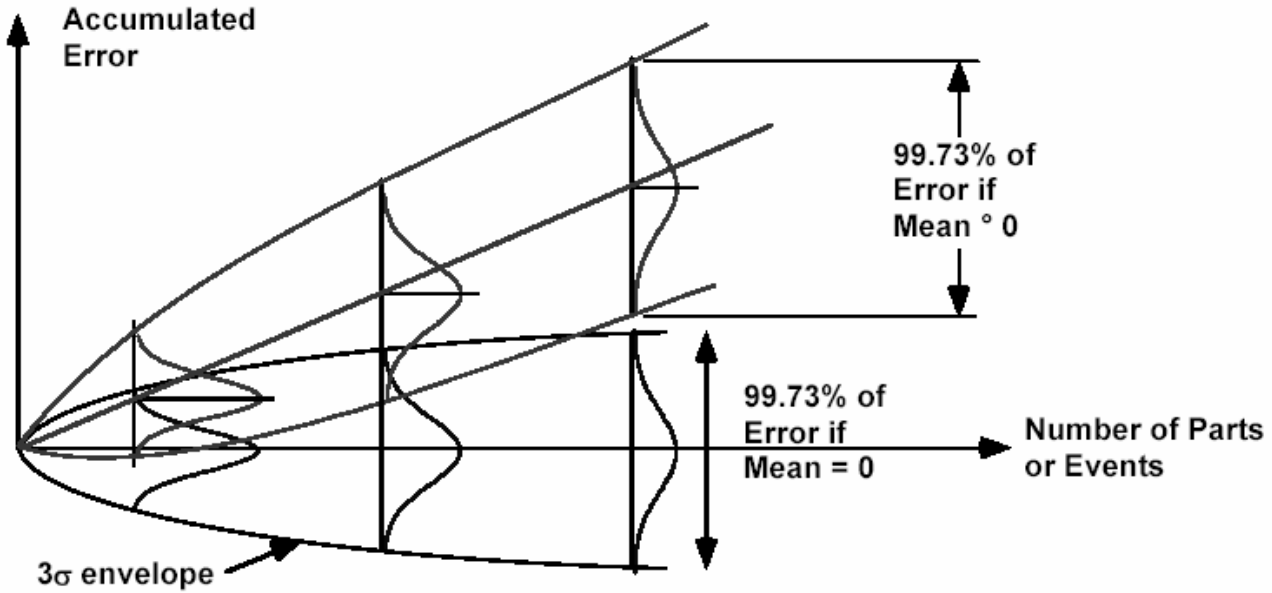
- Worst case tolerancing:
  - assume all errors at extremes
  - errors accumulate linearly w/ # of parts
  - deterministic, not statistical



- Statistical tolerancing
  - assume errors distributed randomly between limits
  - errors accumulate as sqrt of # of parts
    - if mean is equal to nominal dimension!

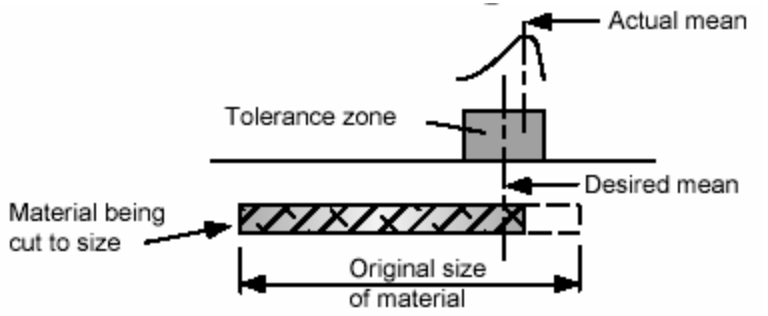
Error Accumulation

- Sums of zero-mean errors accumulate as sqrt(N), because + and - errors cancel
- Sums of non-zero-mean errors accumulate as N, because there are no cancellations

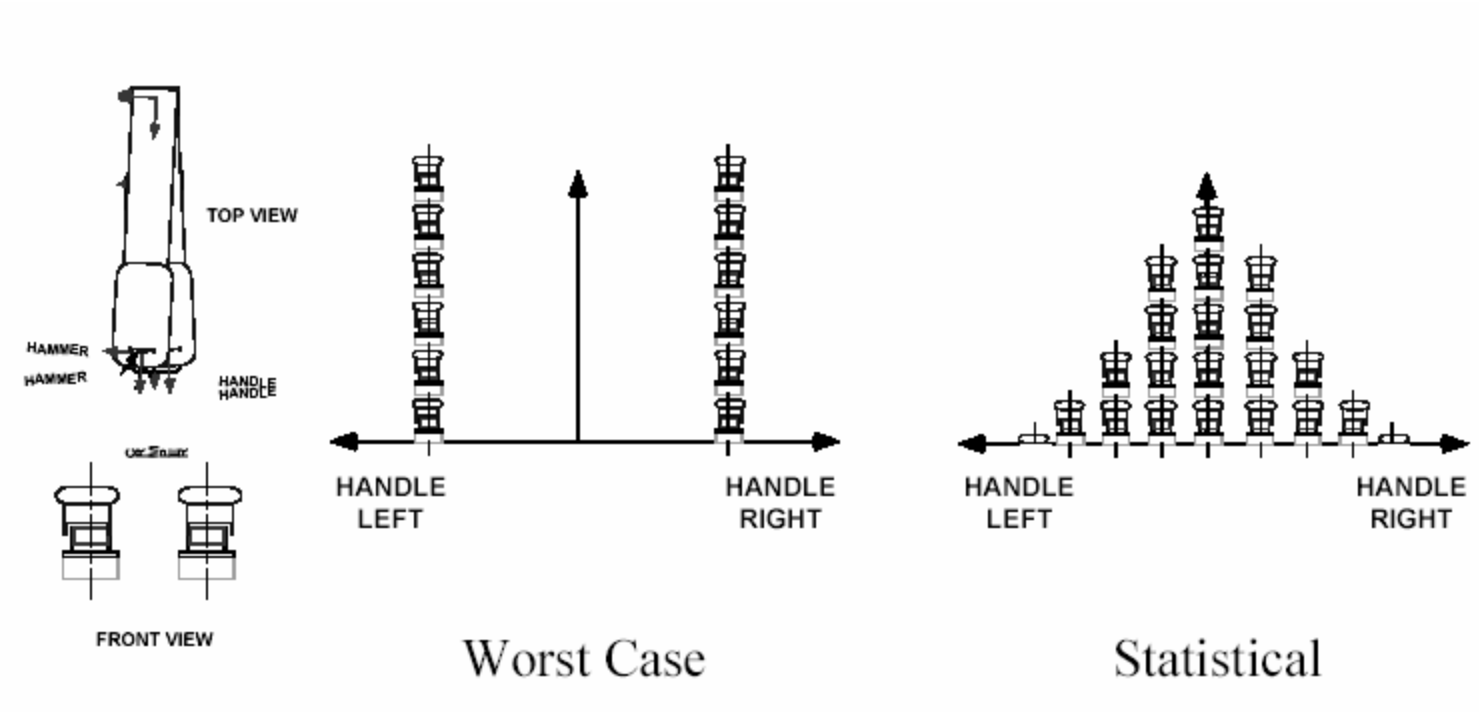


How do Non-zero-mean errors occur?

- Example:
  - operator stops material removal as soon as part enters tolerance zone

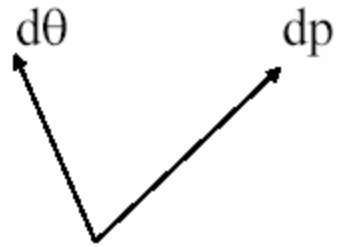


Example - Stapler Variations



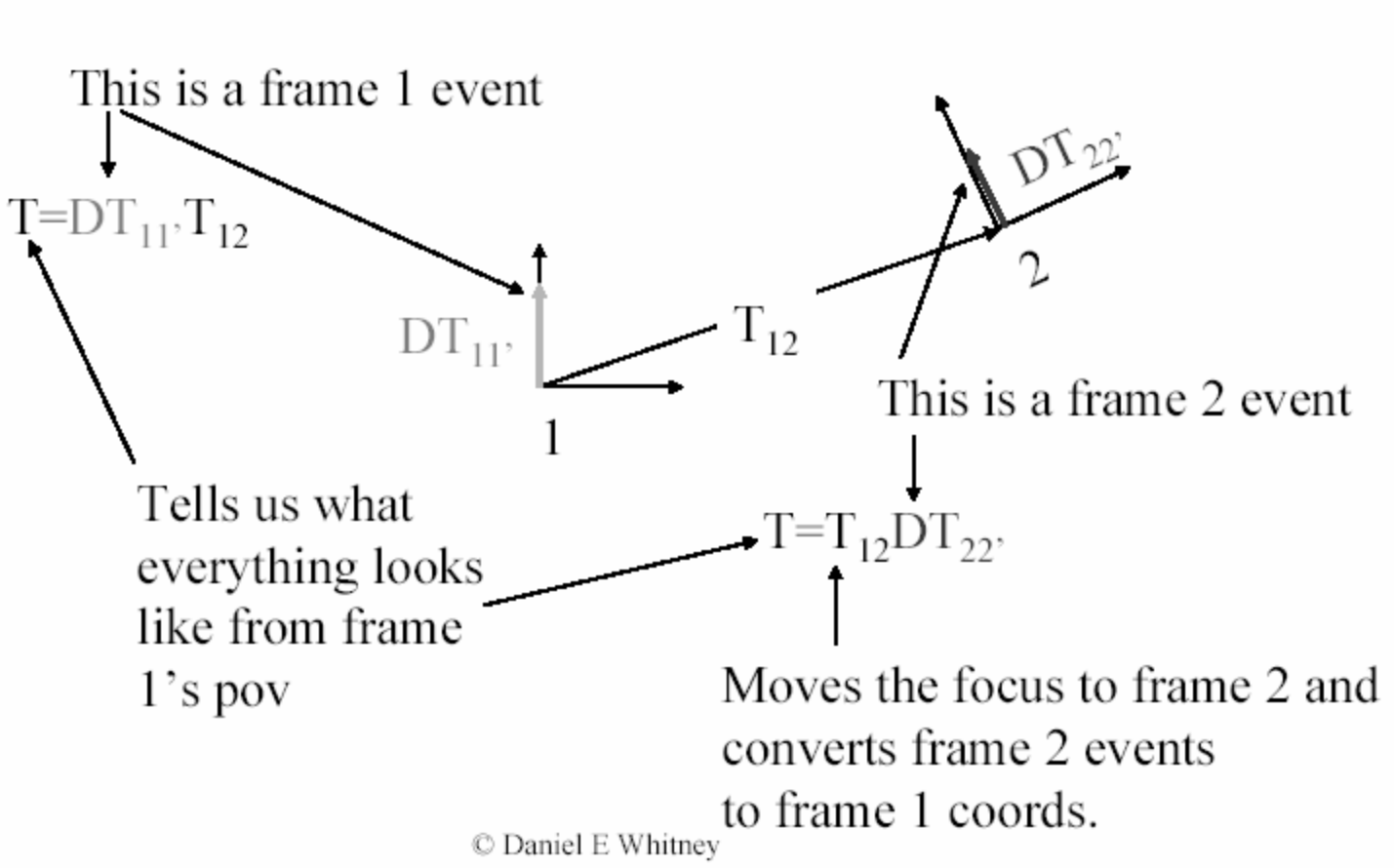
(small) Error Transform

$$DT = \begin{bmatrix} 1 & -\delta\theta_z & \delta\theta_y & dx \\ \delta\theta_z & 1 & -\delta\theta_x & dy \\ -\delta\theta_y & \delta\theta_x & 1 & dz \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

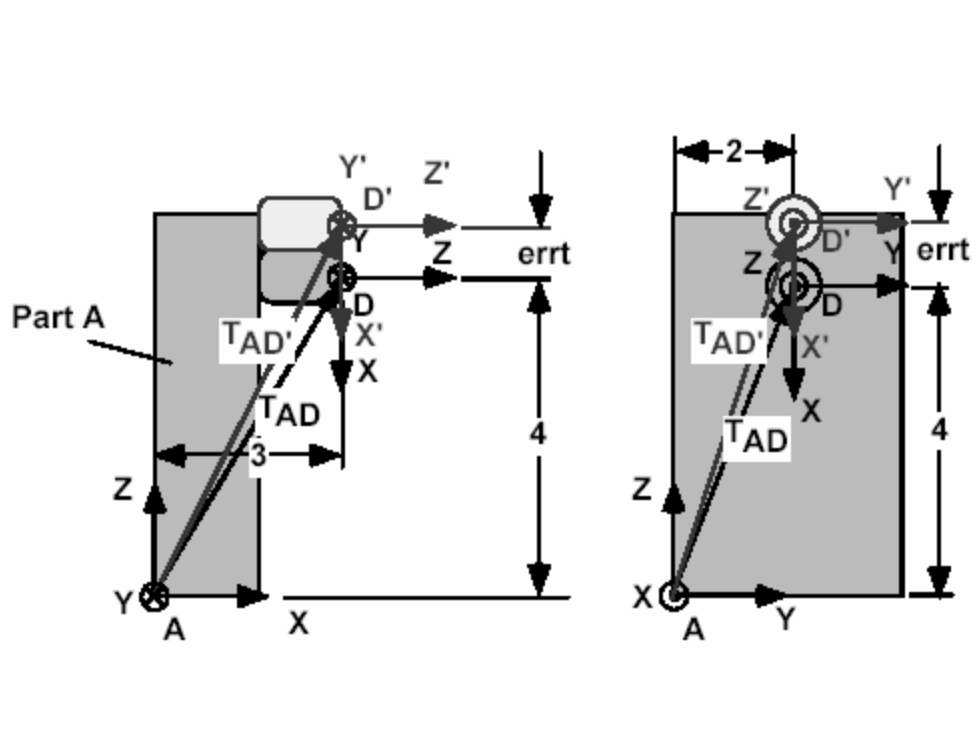


$$T' = T * DT$$

Using Error Transform



Using Error Transform



$>> T_{AD} = trans(3,2,4) * roty(dtr(90))$

% *dtr* converts degrees to radians

$$= \begin{bmatrix} 0 & 0 & 1 & 3 \\ 0 & 1 & 0 & 2 \\ -1 & 0 & 0 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

% First method

$>> DZ = errt$

$>> DT_{AD1} = trans(0,0,DZ)$

$T_{AD'1} = DT_{AD1} T_{AD}$

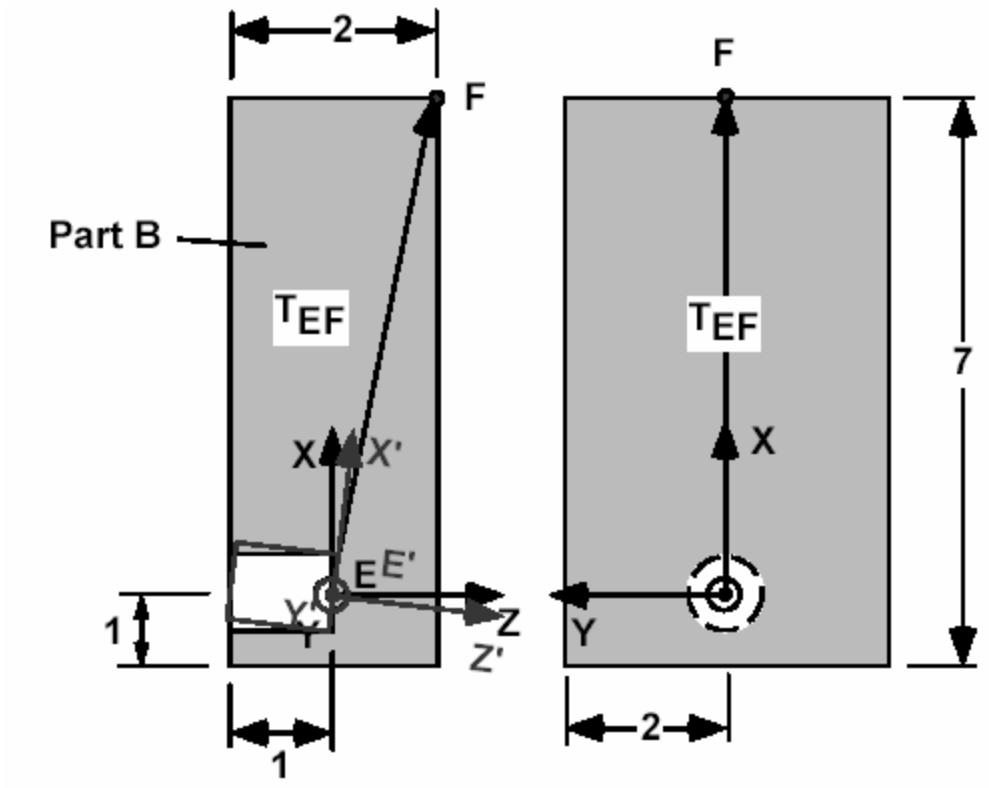
% Second method

$>> DX = errt$

$>> DT_{AD2} = trans(-DX,0,0)$

$>> T_{AD'2} = T_{AD} DT_{AD2}$

Using Error Transform - Part 2



$$>> T_{EF} = trans\ (6,0,1)$$

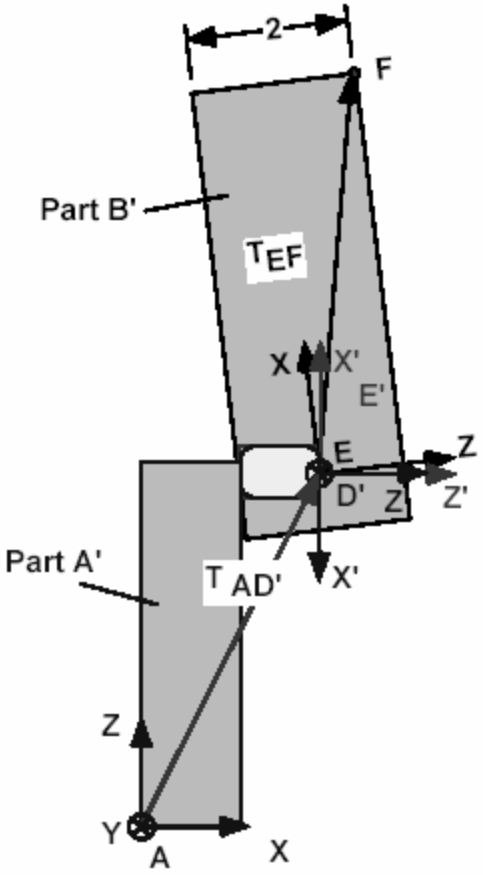
$$= \begin{bmatrix} 1 & 0 & 0 & 6 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$>> T_{EE'} = roty\ (dtr\ (-erra))$$

$$>> T_{E'E} = roty\ (dtr\ (erra))$$

$$>> T_{E'F} = T_{E'E} T_{EF}$$

Using Error Transform - Part 2



$$>> T_{DE} = rotz(dtr(180))$$

$$= \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$>> T_{AF} = T_{AD} T_{DE} T_{EF}$$

$$= \begin{bmatrix} 0 & 0 & 1 & 4 \\ 0 & -1 & 0 & 2 \\ 1 & 0 & 0 & 10 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$>> T'_{AF} = T_{AD'} T_{D'E'} T_{E'F}$$

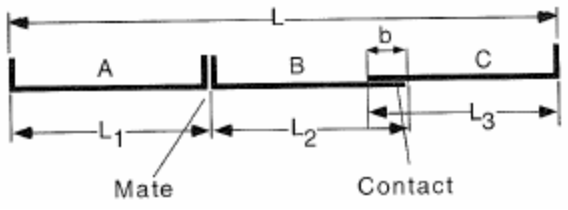
$$\%T_{D'E'} = T_{DE}$$

Datum Flow Chain

- Delivery chain for a Key Characteristic
- Liaison diagram assembly joints:
  - Mates: pass dimensional constraint
  - Contacts: provide support or off-axis constraint

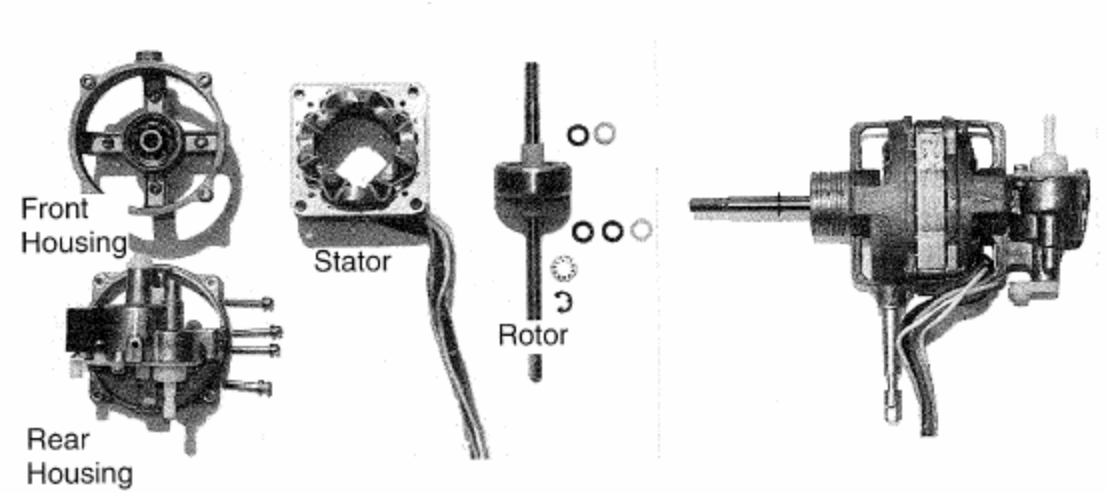
TABLE 8-1. Distinguishing Mates and Contacts

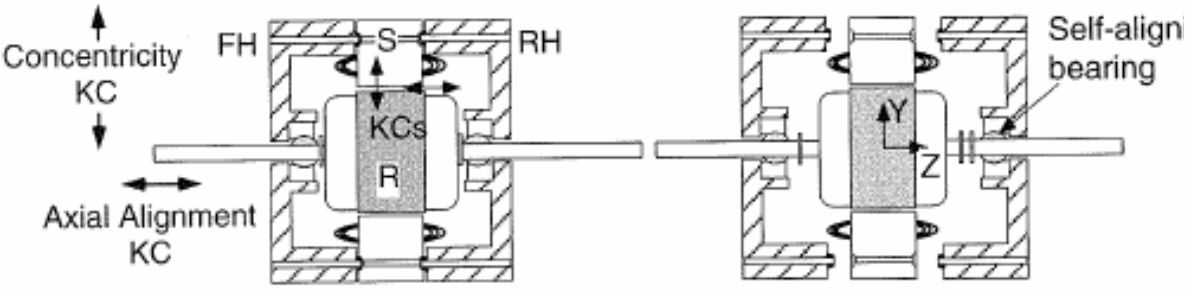
Function	Mate?	Contact?	Example
Full six dof constrained	Yes	No	Square peg in square hole
No dof constrained	No	Yes	Nuts attaching wheel to axle hub
Some dof constrained along a KC	Yes along KC directions	Yes along non-KC directions	Rim on axle hub; slip joint in sheet metal

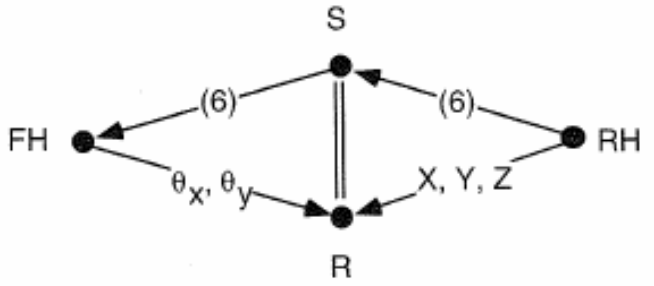


Example Assemblies

- Fan motor







Fan Motor Example