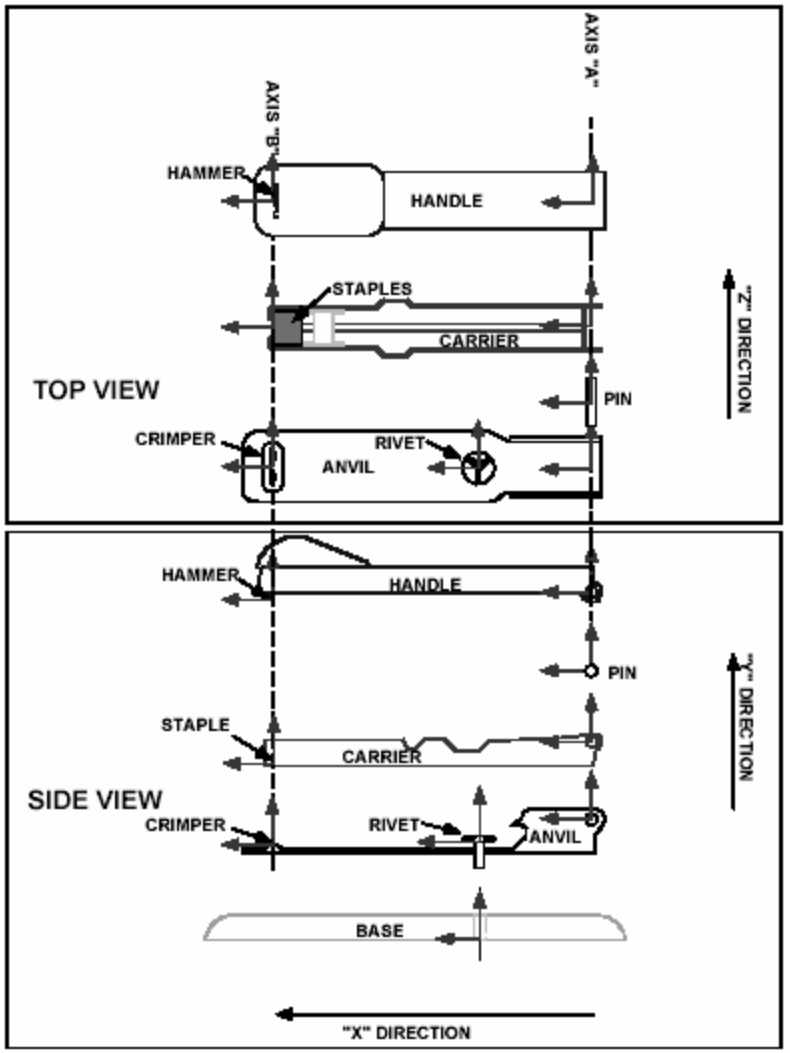
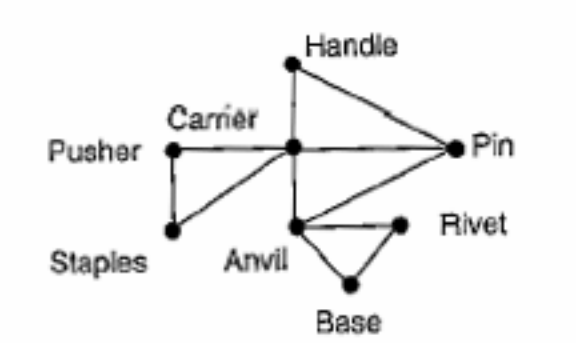
Analyzing the Product

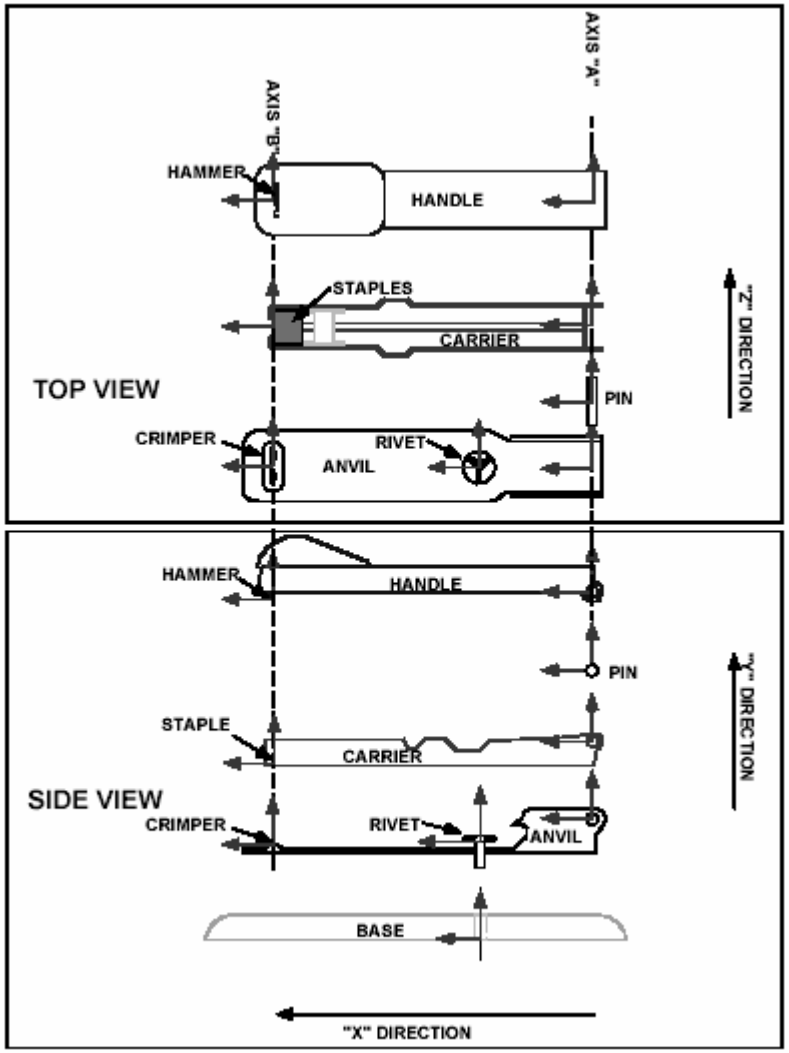
- Stapler example:



Analyzing the Stapler

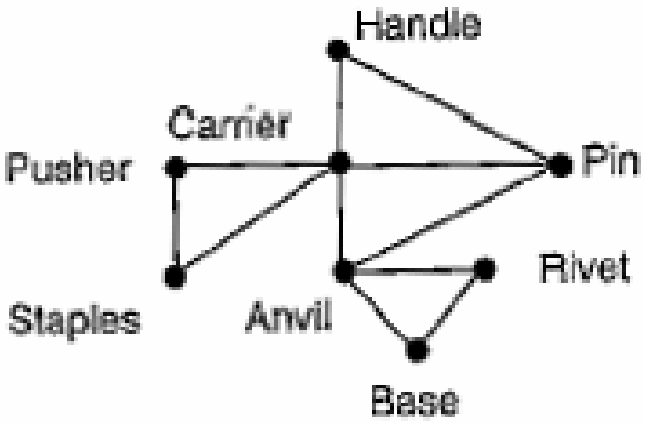
- What would cause the stapler not to work?
- What is the "architecture" of the stapler? (how parts are laid out, functions, arrangement in space)
- Liaison Diagram (p.4)

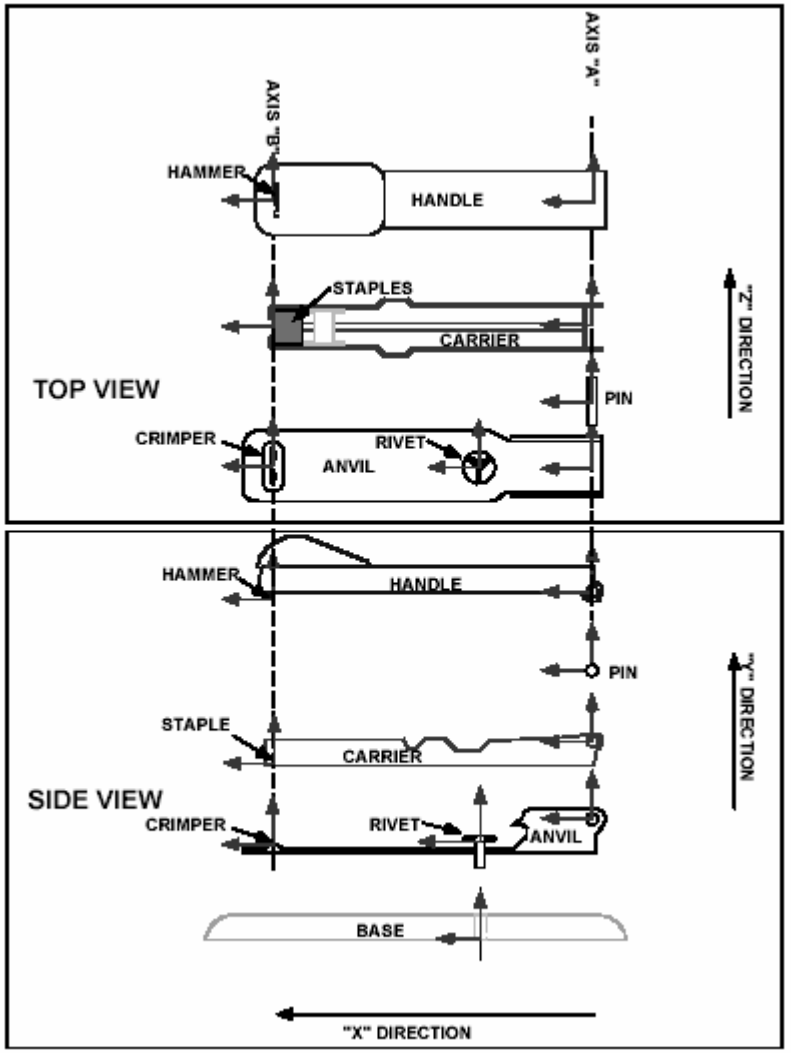




Liaison Diagram

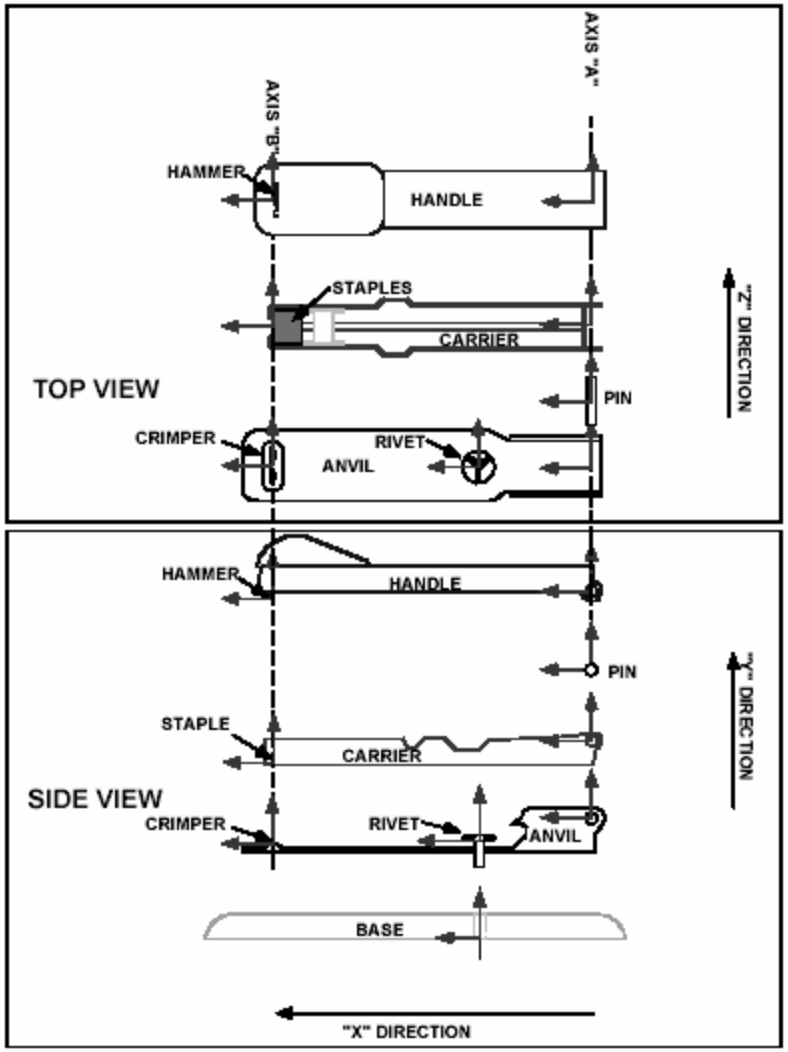
- rivet connects anvil to base
- pin connects anvil, carrier, and handle
- carrier connects pusher and staples





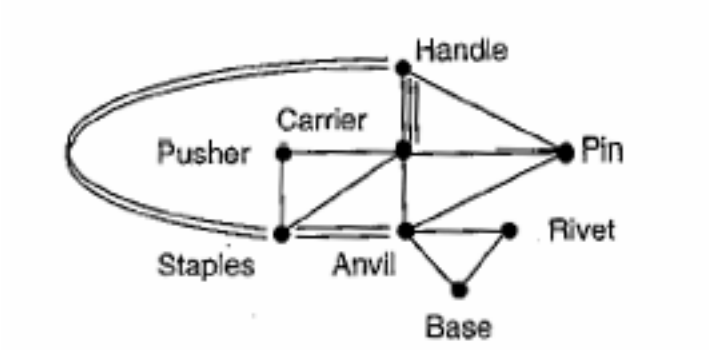
Stapler Example

- What are some "Key Characteristics" that could affect function?
  - *–In X direction:*
    - *•position of hammer*
    - *•thickness of hammer*
    - *•anvil length*
    - *•position of pin & holes*



Stapler Example

- Liaison Diagram with Key Characteristics



Manufacturing and Assembly Variation

- Engineering design of an assembly
  - Nominal design
  - Variation design
  - Process design

Nominal Design

- Determine ideal locations and orientations of parts
- Define mutual positioning constraints

Variation Design

- Determine allowable variation in location and orientation
- How much variation in each constraint can be tolerated and still achieve the key characteristics?

Process Design

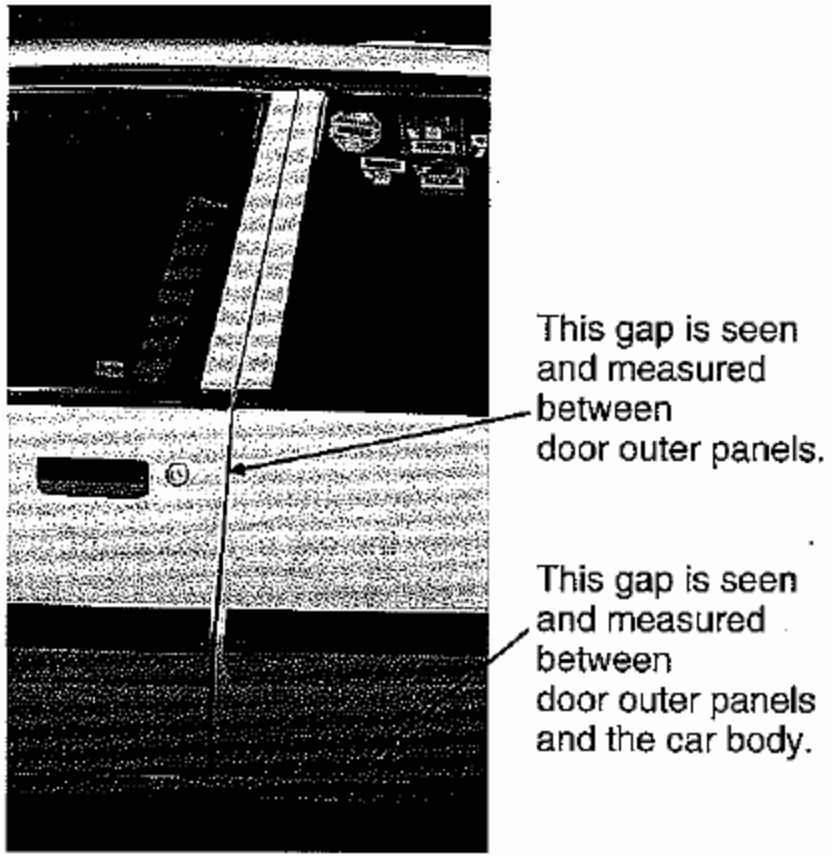
- Determine fabrication and assembly processes that will contribute no more than the tolerable variation
- May require loosening allowable variation if no economical process exists

Variation Risk Management (VRM)

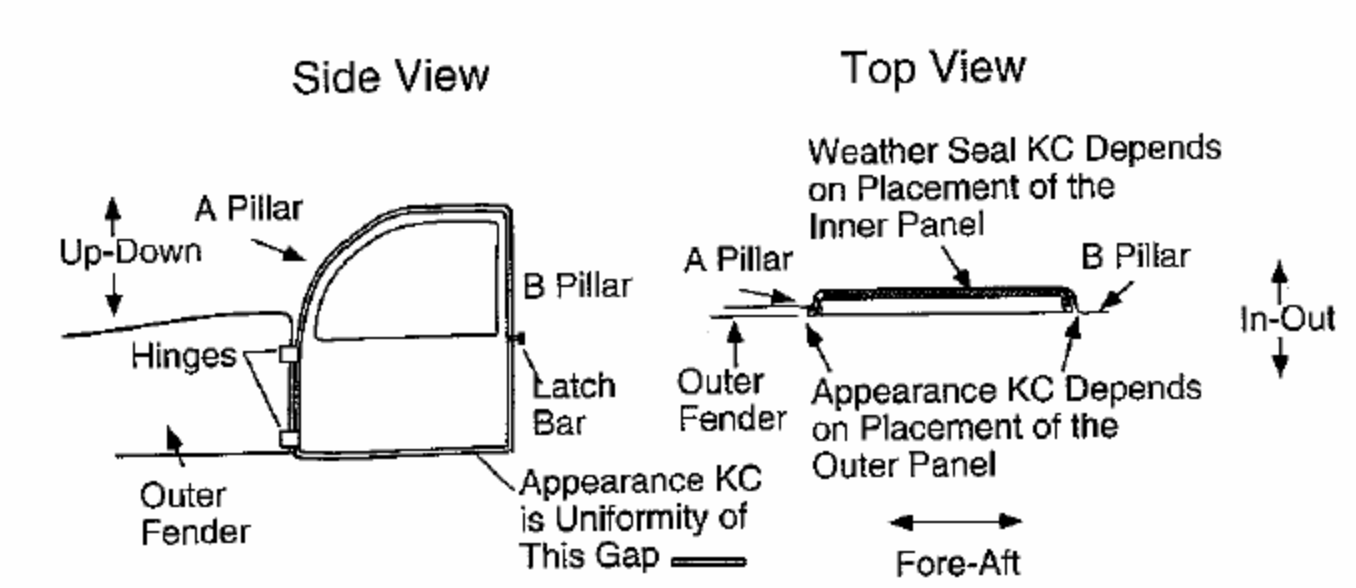
- Nominal Design, Variation Design, Process Design together make Variation Risk Management
- Very hard for many products

Example - Car Doors

- Door gap KC
- Weatherstripping KC

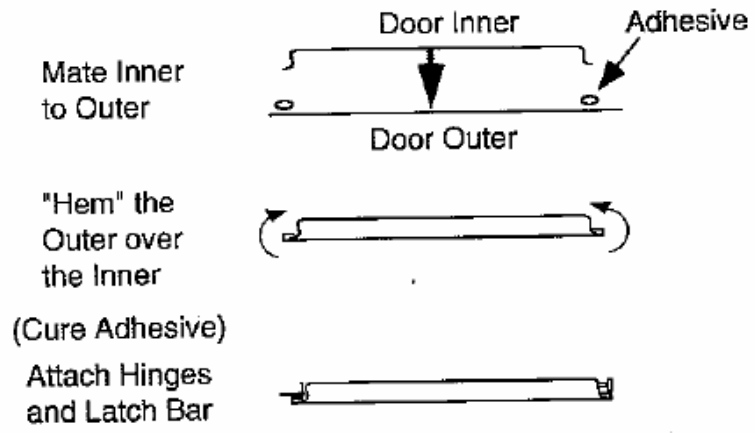


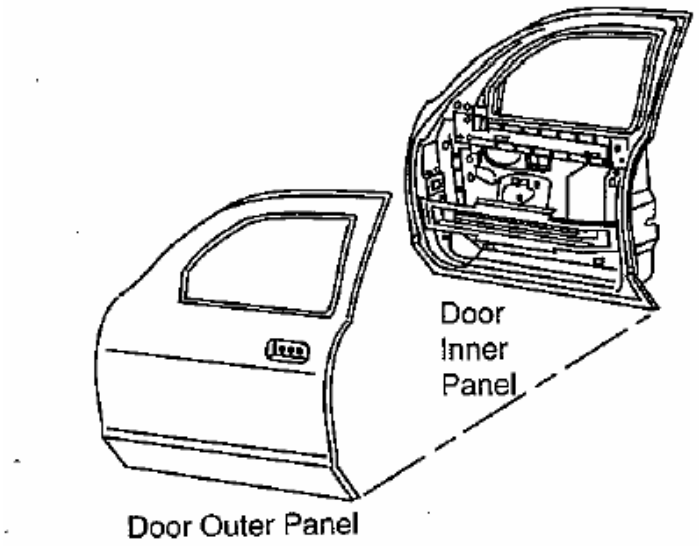
Car Door Example



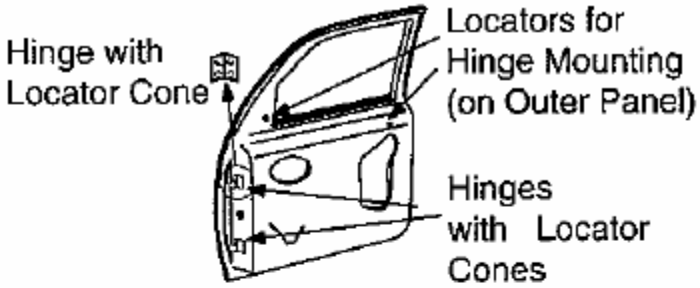
Car Door Example

- Making a door

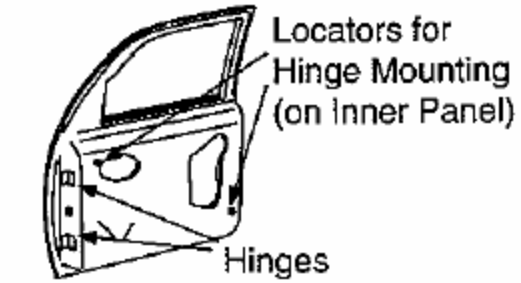




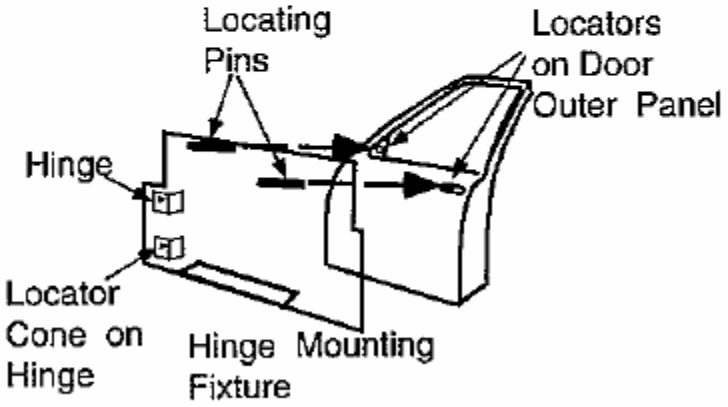
Car Doors - Mounting



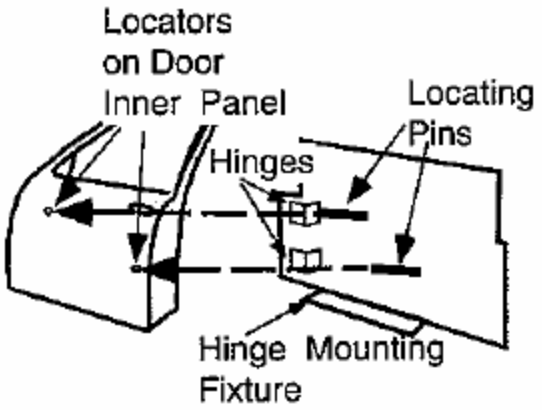
GM Door and Hinges



Ford Door and Hinges

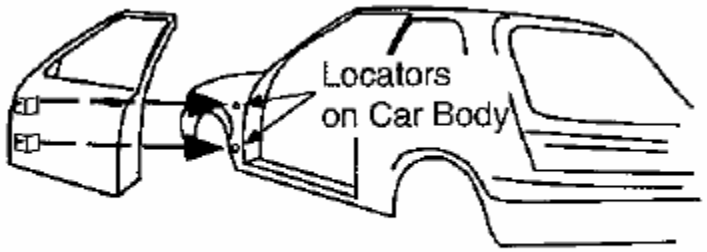


GM Method of Mounting
Hinges on Doors

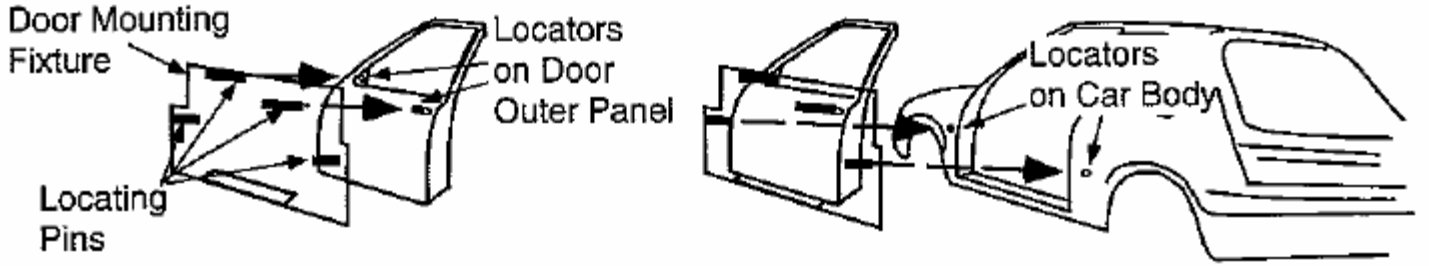


Ford Method of Mounting
Hinges on Doors

Car Doors - Mounting



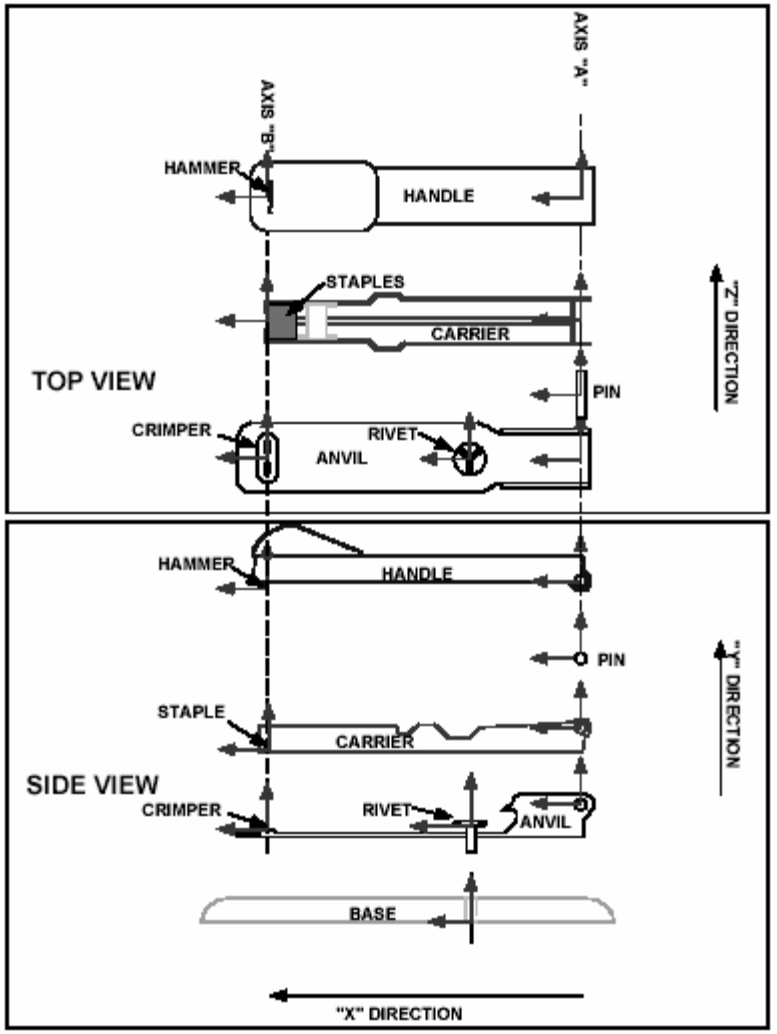
GM Method of Mounting Doors to Car Bodies



Ford Method of Mounting Doors to Car Bodies

Mathematical Modeling of Assembly

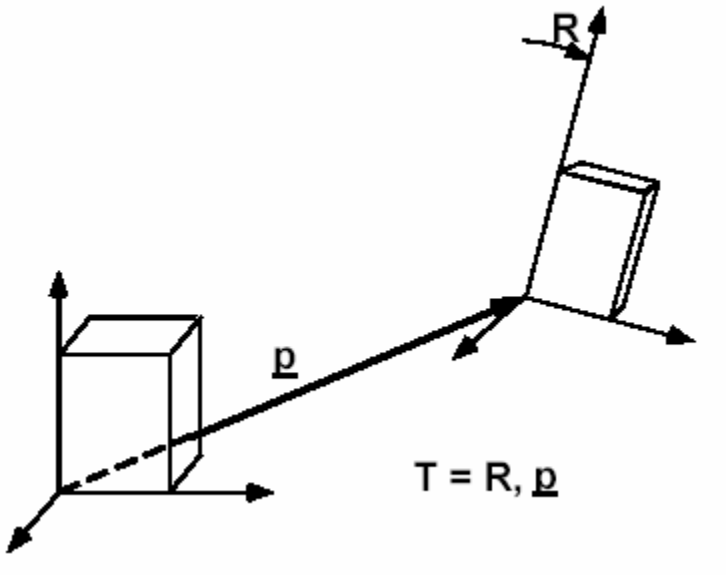
- Coordinate frames
  - each part has a base coordinate frame
- Relationships between parts are expressed as 4x4 matrix transforms



Matrix Math

- 4x4 matrices relate adjacent frames
- Matrix contains rotational part and translational part
- Translation occurs first, so rotation does not change position of new frame

Basic Translation and Rotation



$$T = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T = \begin{bmatrix} R & p \\ 0^T & 1 \end{bmatrix}$$

Watch Transform Ordering!

$$T = \begin{bmatrix} R & p \\ 0^T & 1 \end{bmatrix}$$

$$= \begin{bmatrix} I & p \\ 0^T & 1 \end{bmatrix} * \begin{bmatrix} R & 0 \\ 0^T & 1 \end{bmatrix}$$

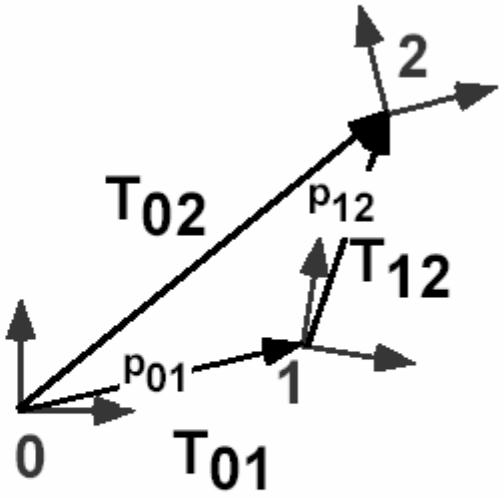
$$\neq \begin{bmatrix} R & 0 \\ 0^T & 1 \end{bmatrix} * \begin{bmatrix} I & p \\ 0^T & 1 \end{bmatrix} \quad !!!$$

Composite Transforms

$$T_{02} = T_{01}\, T_{12}$$

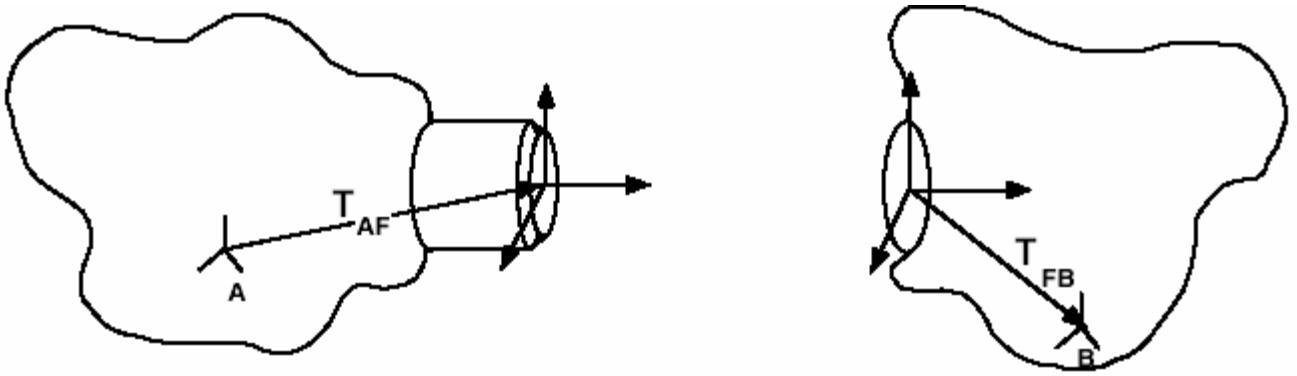
$$T_{02} = \begin{bmatrix} R_{01} & p_{01} \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} R_{12} & p_{12} \\ 0^T & 1 \end{bmatrix} =$$

$$\begin{bmatrix} R_{01}R_{12} & R_{01}p_{12}+p_{01} \\ 0^T & 1 \end{bmatrix}$$

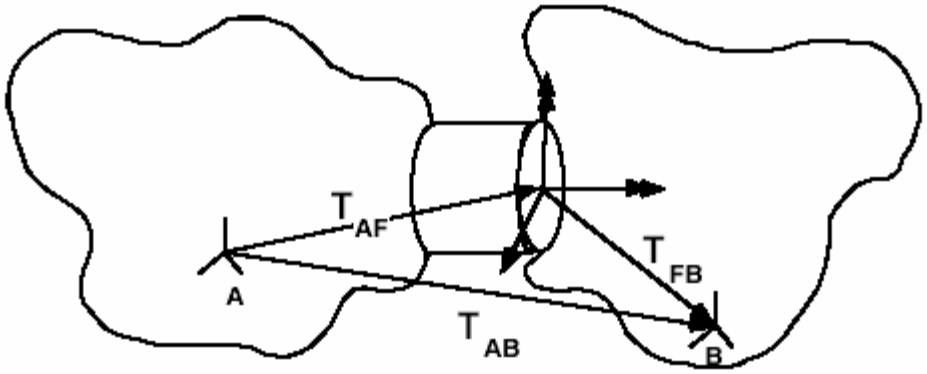


T_{01} locates frame 1 in frame 0 coordinates
T_{12} locates frame 2 in frame 1 coordinates
T_{02} locates frame 2 in frame 0 coordinates

Nominal Mating of Parts



Parts A and B are mated by joining two features



The nominal location of part B can be calculated from the nominal location of part A using 4x4 transform math