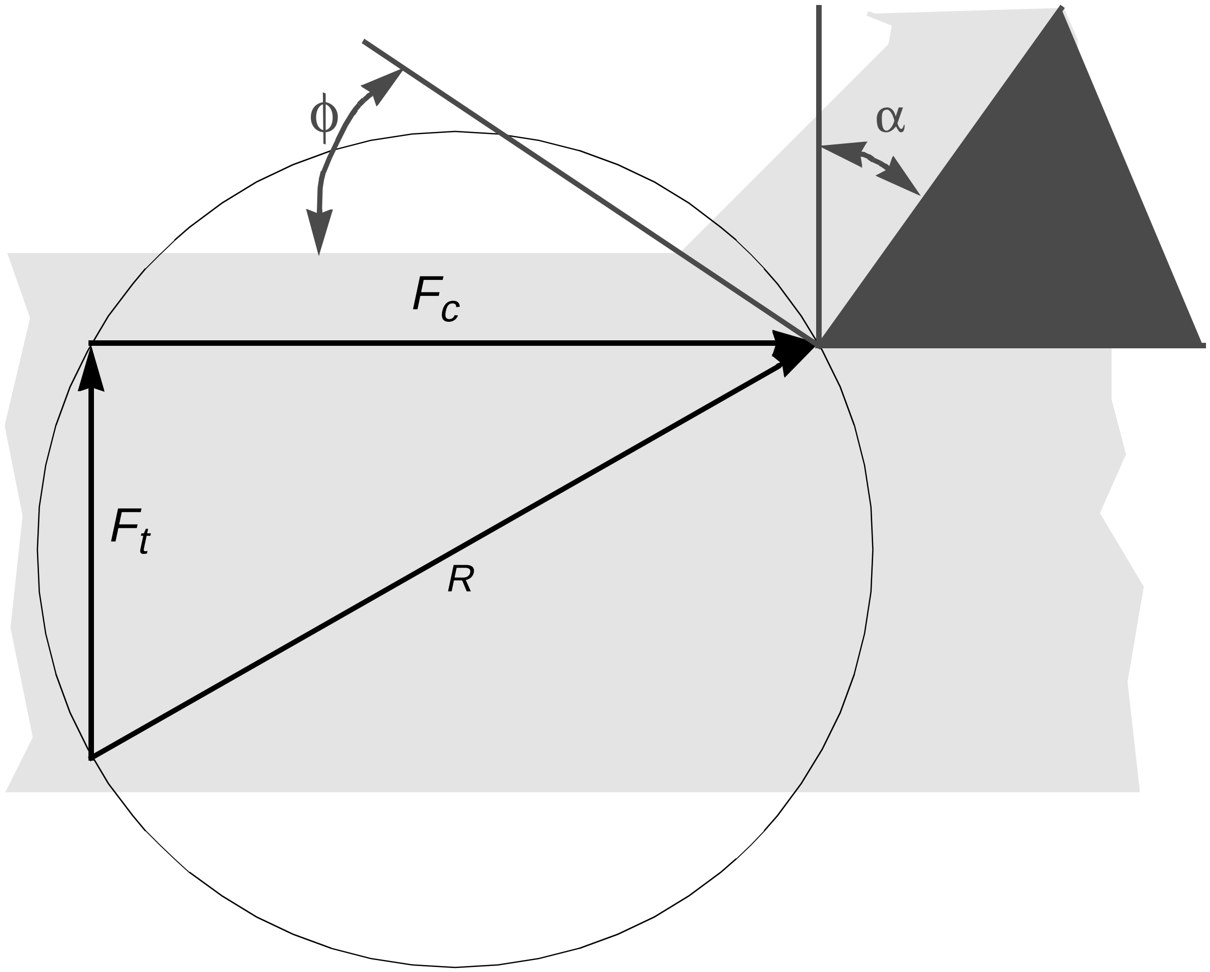
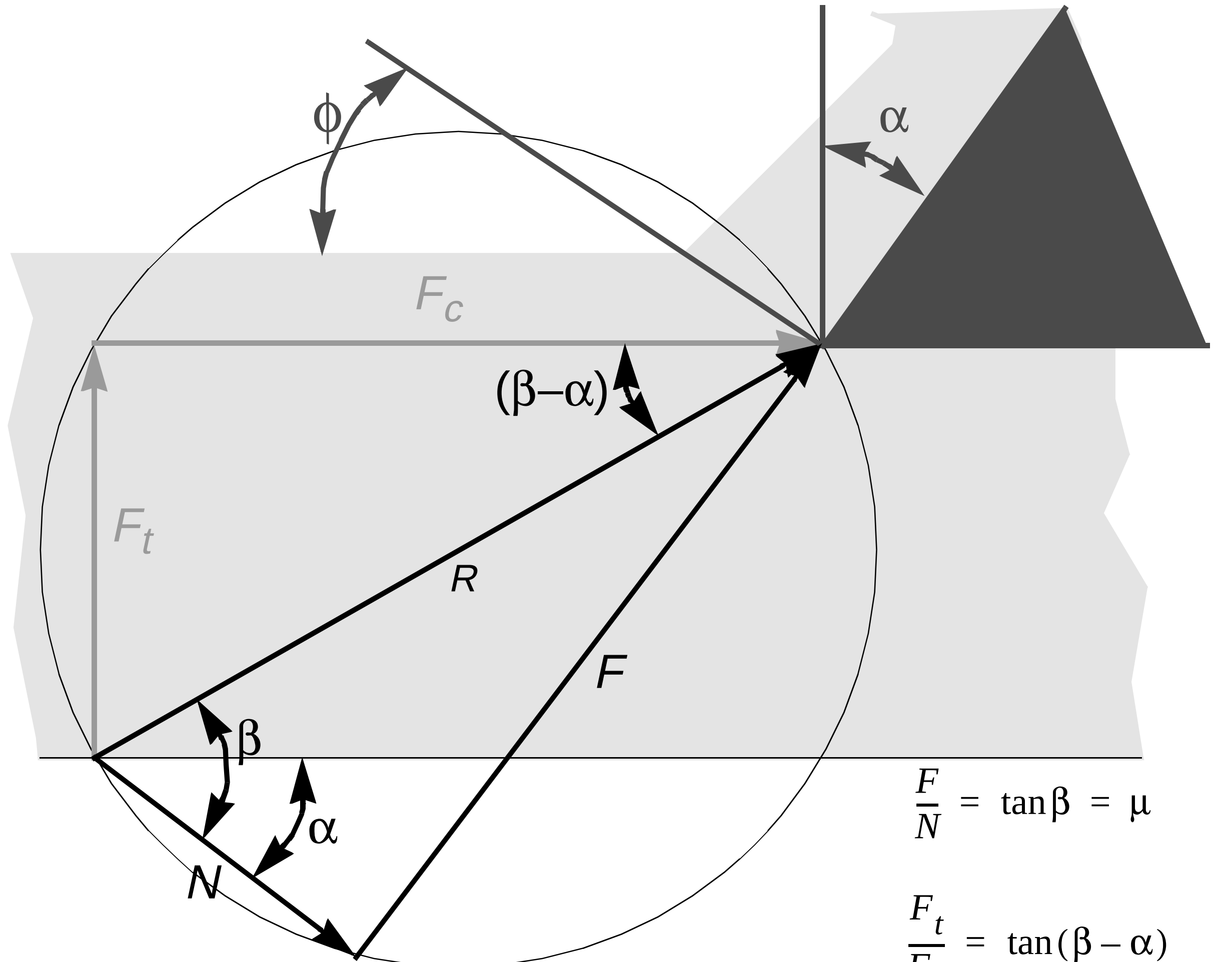
Machining

- Recap of physics.
- Models and reality: comments
- Chip formation
- Tool wear
- Cutting tools and tooling materials

Force diagram 1



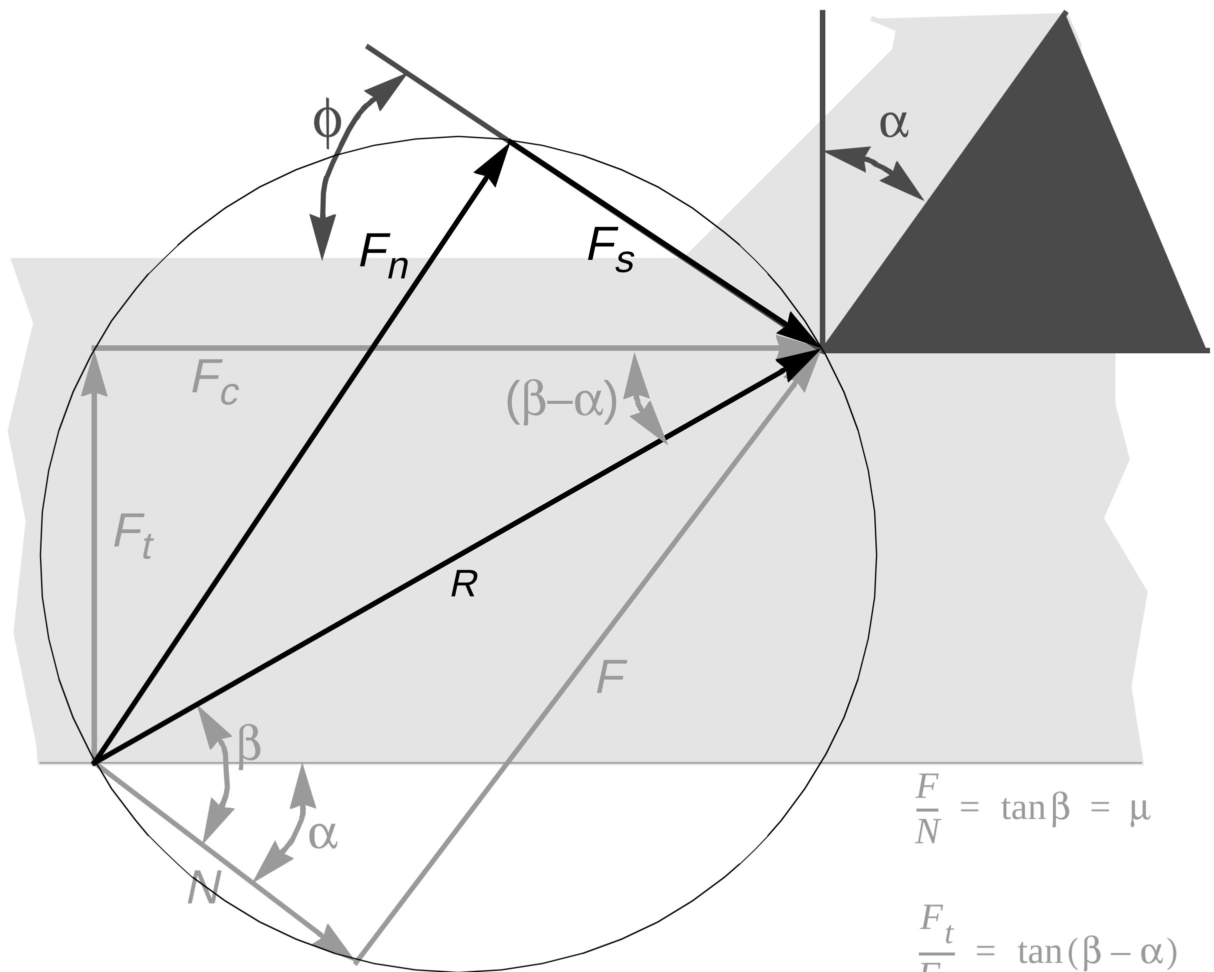
Force diagram 2



$$\frac{F}{N} = \tan\beta = \mu$$

$$\frac{F_t}{F_c} = \tan(\beta - \alpha)$$

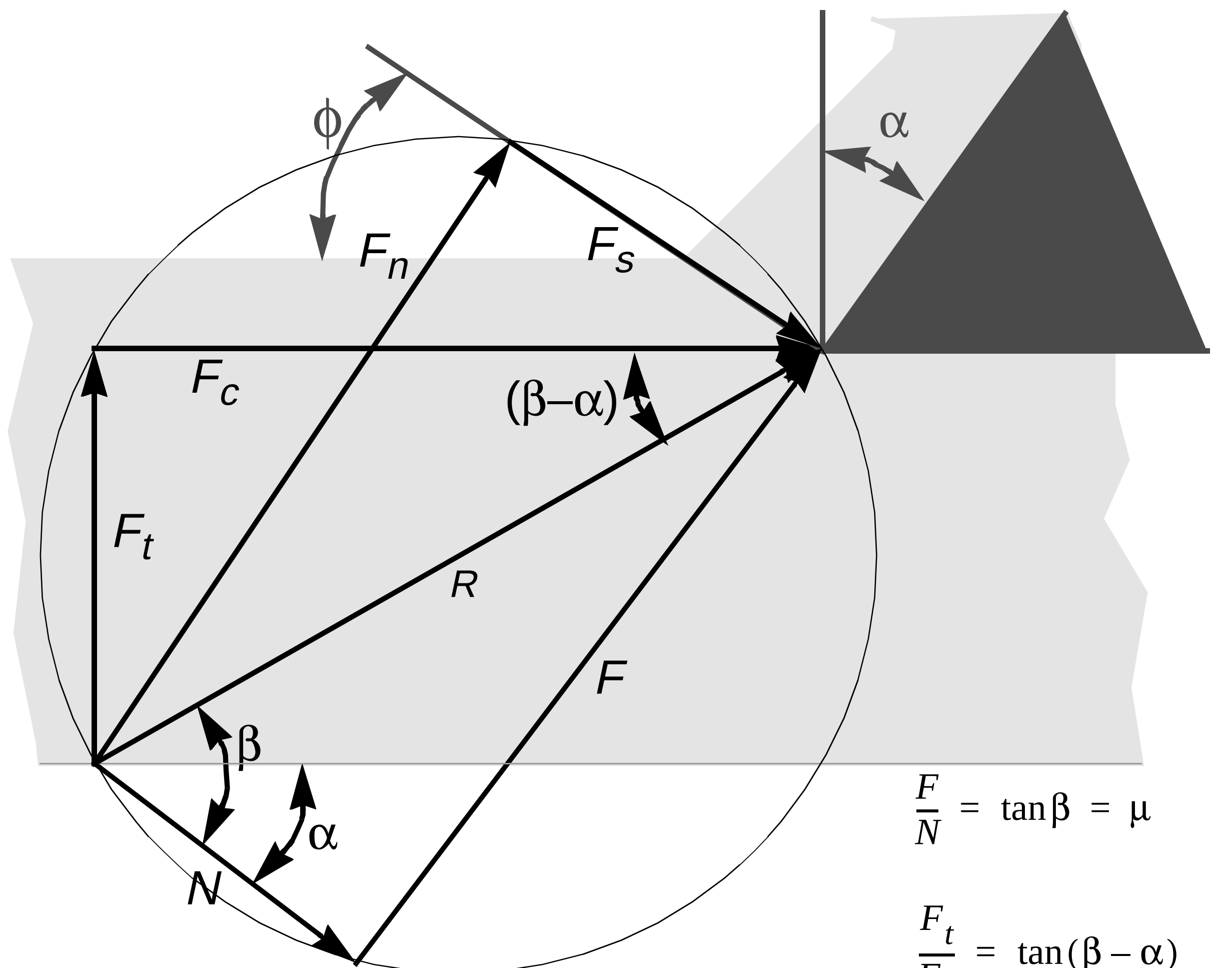
Force diagram 3



$$\frac{F}{N} = \tan\beta = \mu$$

$$\frac{F_t}{F_c} = \tan(\beta - \alpha)$$

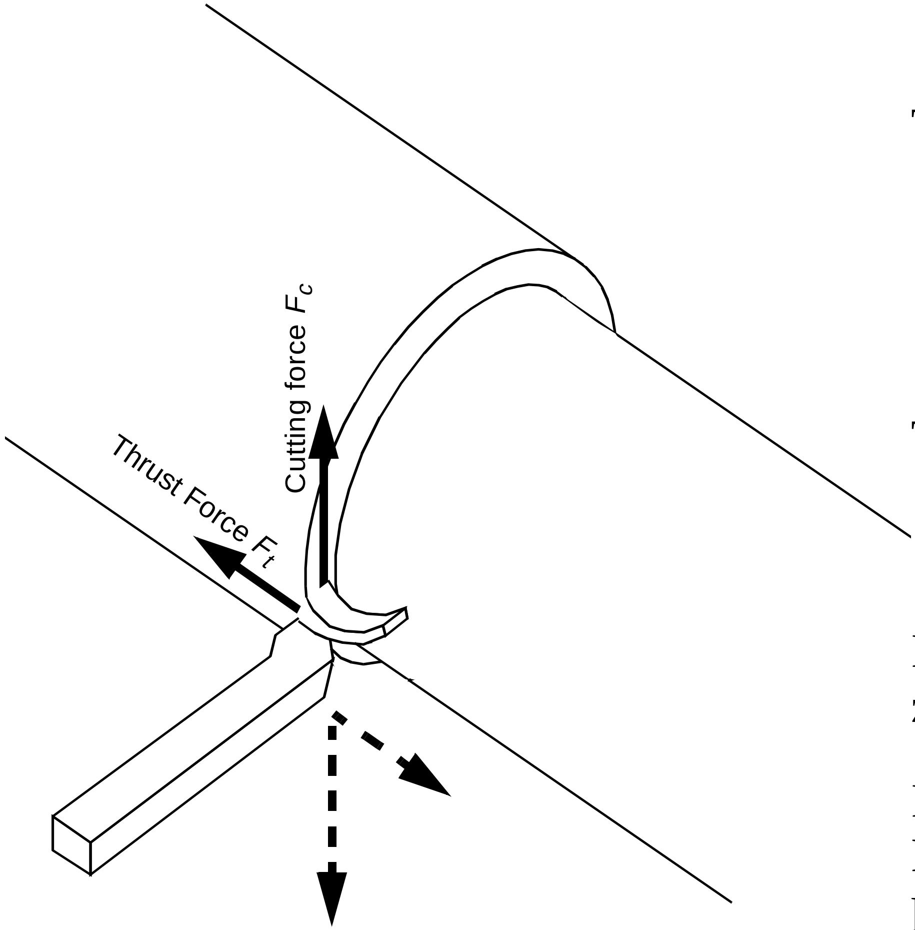
Merchant's diagram



$$\frac{F}{N} = \tan\beta = \mu$$

$$\frac{F_t}{F_c} = \tan(\beta - \alpha)$$

Thrust Force



The thrust force is important:

- Pushes tool away from cut
- Affects tool holder design
- Affects tool vibration

Thrust is given by:

$$F_t = F_c \tan(\beta - \alpha)$$

If $\beta = \alpha$, then thrust goes to zero!!!

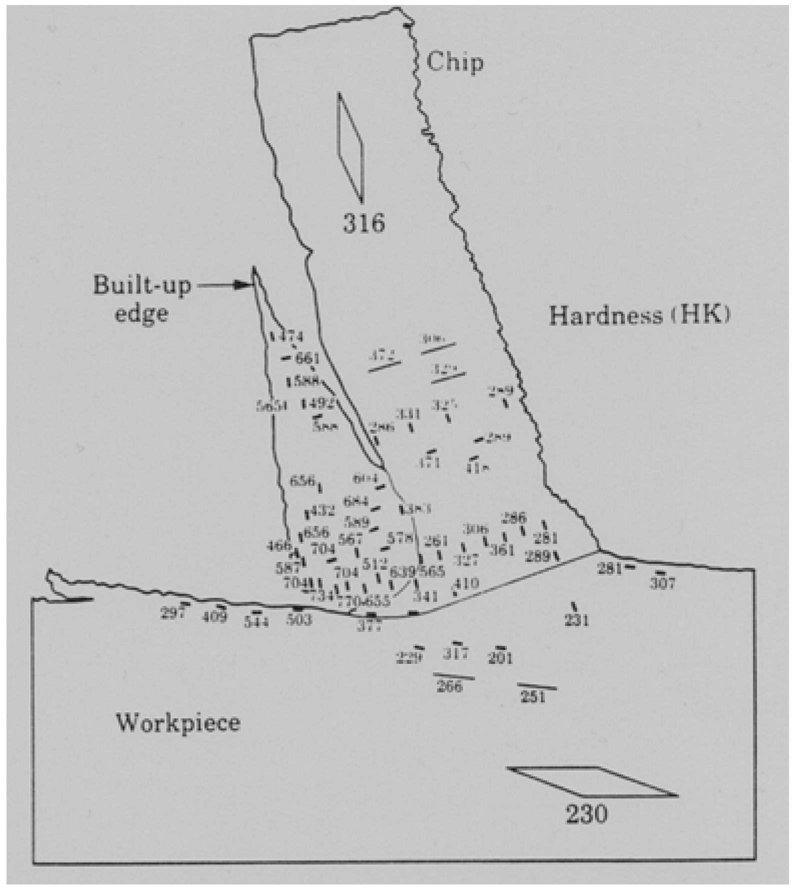
If $\beta \leq \alpha$, then thrust is reversed! Keeps tool engaged in cut. Use high α and lots of coolant for very thin cuts.

Models and reality:

- Remember that we have studied slow, orthogonal cutting with many simplifying assumptions:
  - Material properties unchanging (no strain hardening, strain rate dependence).
  - Temperature effects ignored.
  - Simple friction model.
- These equations provide a trend only! Form basis for experimental analysis.
- More accurate correlations do exist.

Hardness distribution in the cutting zone for 3115 steel

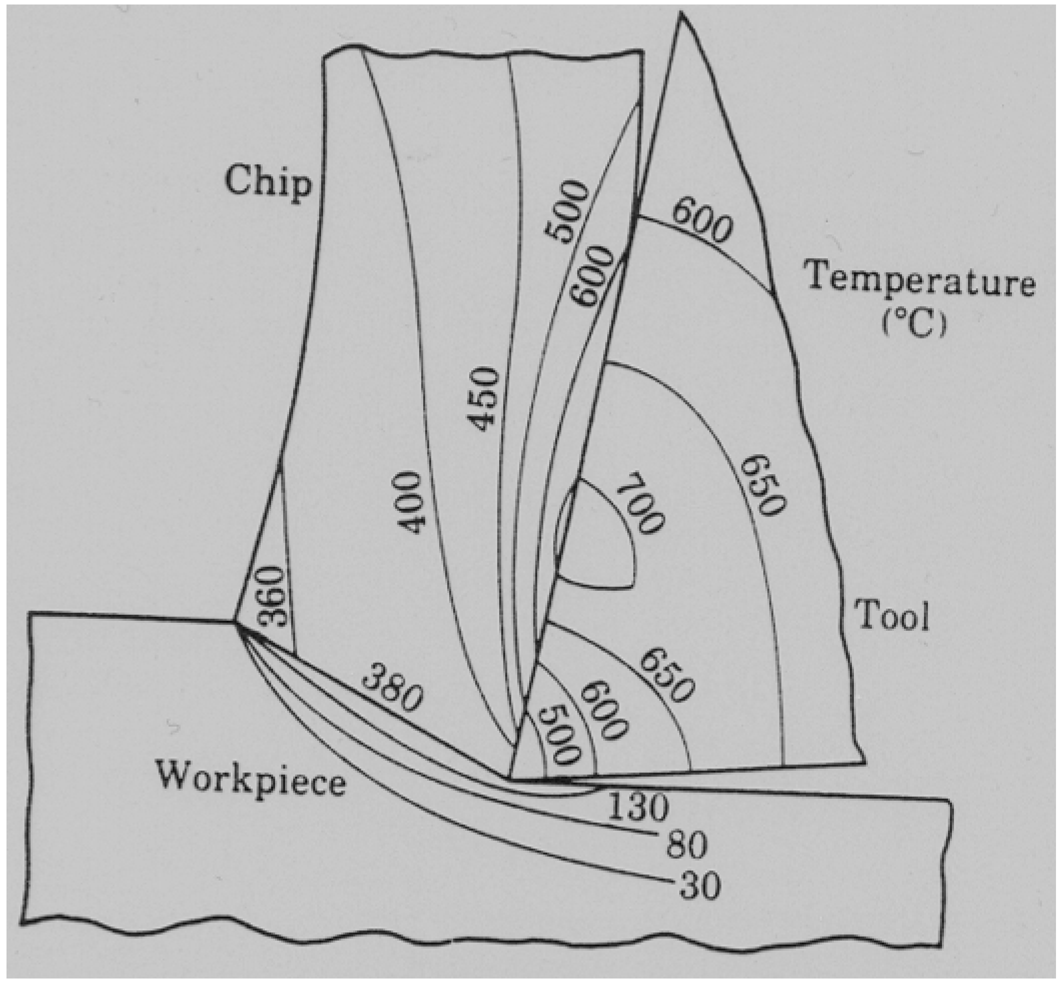
Note that some regions in the built up edges are as much as three times harder than the bulk metal



Typical temperature distribution in the cutting zone

Note the steep temperature gradients within the tool and the chip.

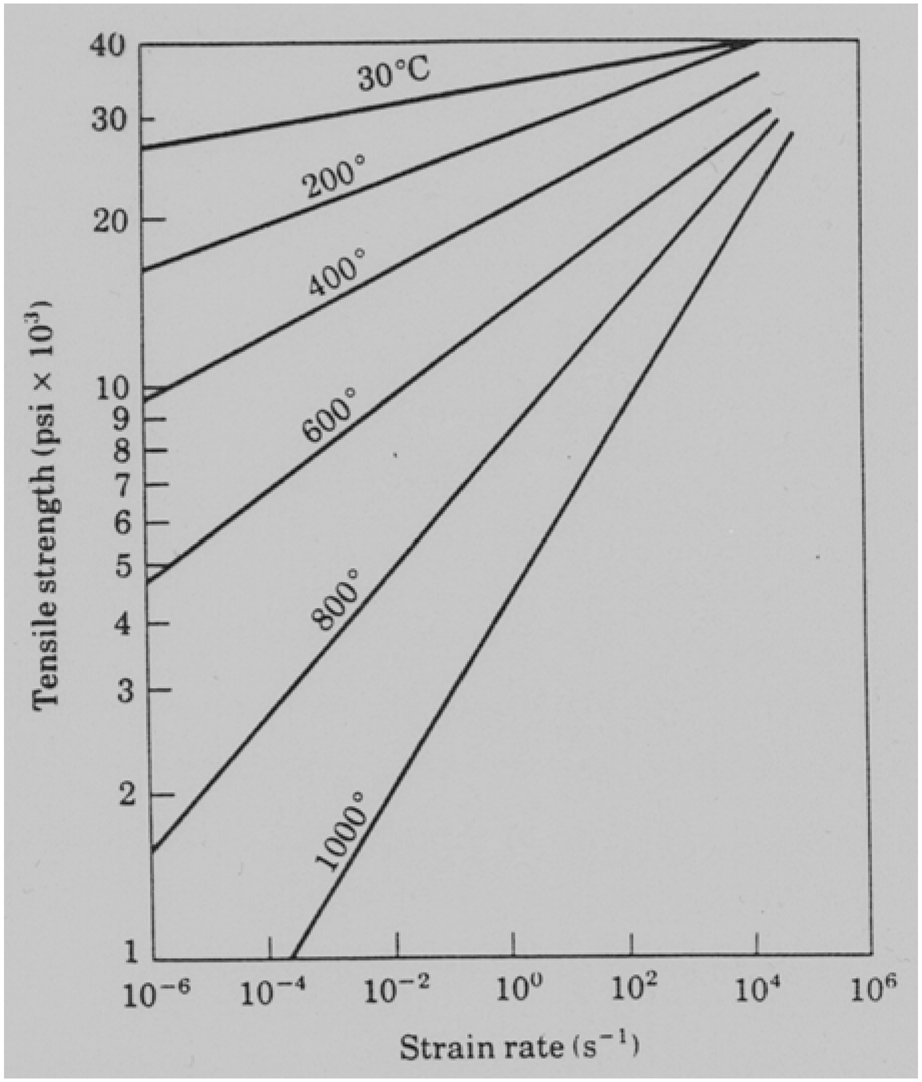
[source: G. Vieregge]



Strain Rate vs Ultimate tensile strength

for Aluminum. Note that as the temperature increases, the slopes of the curves increase. Thus, strength becomes more and more sensitive to strain rate as temperature increases.

[source: J H Hollomon]



Cutting Models

Analytical model of orthogonal cutting:

Examples of friction angles and shear stresses for various workpiece and tool material combinations are presented in Table A.1

Table A.1. Friction angles and shear stresses for various workpiece and tool material combinations

Tool Material	Work Material	Apparent Friction Angle β (deg)	Shear Stress τ_s (ksi)
HSS	copper	37	45.4
HSS	SAE 1018 steel	35	82.3
HSS	SAE 1010 steel	36	69.5
HSS	6061-T6 aluminium	36	41.2

Appendix A.2. Empirical Model

Empirical models are derived by curve fitting a function with experimental data. However, in order to be correct, the empirical model must have some physical basis. An example of an empirical model for the cutting force components in the general three-dimensional cutting case is given by:

$$F_c = K_c b h^{1-m_c} \quad (A.1)$$

$$F_f = K_f b h^{1-m_f} \quad (A.2)$$

$$F_r = K_r b h^{1-m_r} \quad (A.3)$$

where

$$b = d / \sin(\chi) \quad (A.4)$$

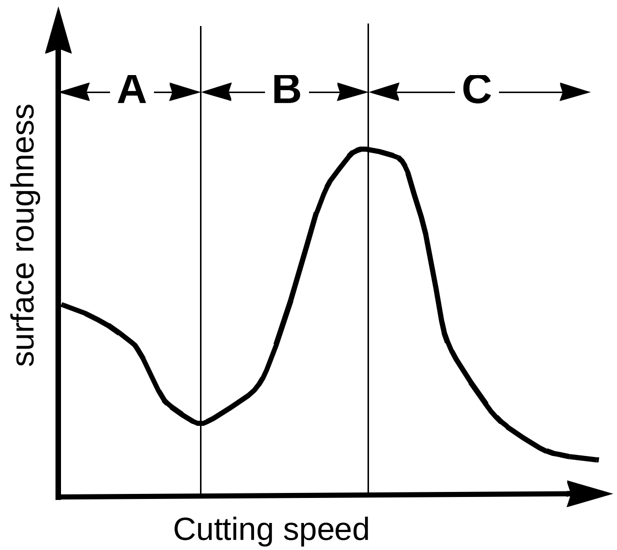
$$h = f \sin(\chi) \quad (A.5)$$

and K_c, K_f, K_r, m_c, m_f and m_r are empirical constants which are determined experimentally. In general, a different set of constants must be found for each workpiece/tool material combination and for each tool geometry. In this model, the "K" factors are related to material strength and the "bh^{1-m}" factors are related to the cutting area. Thus, the above model resembles $F = \tau_s$ x Area, which is intuitively correct and has a physical basis. The geometrical parameters included in the above equations are illustrated in Figure A.1.

Chip formation

- Continuous Chips
  - Bad for automation, so use **CHIP BREAKERS**
  - Secondary shear zone, increased friction
  - Happens with ductile materials, high speed
- Built-up Edge
  - Extreme plasticity and welding between tool and work.
  - Also bad for automation.
- Serrated Chips
  - Forms when thermal conductivity is low or material softens with temperature.
  - Wears tools - eg., titanium, stainless steel
- Discontinuous Chips (Good chips)

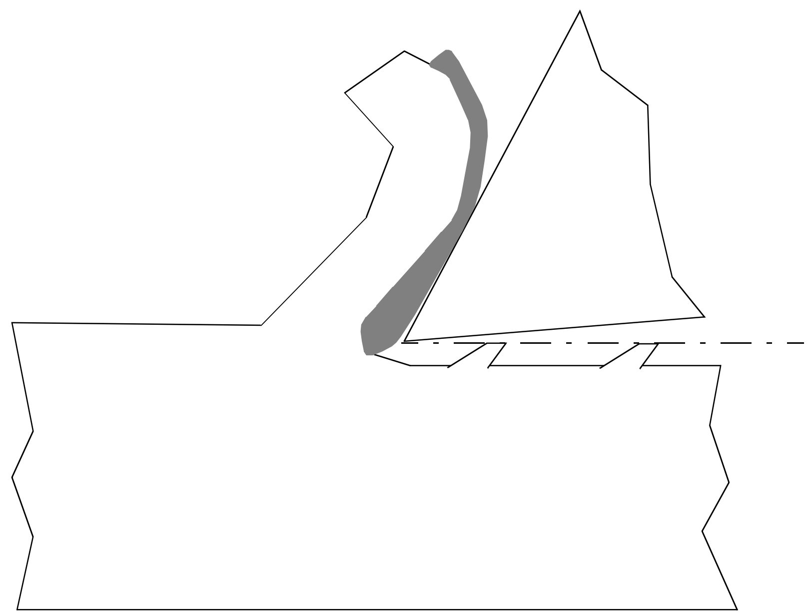
Surface roughness Vs Speed



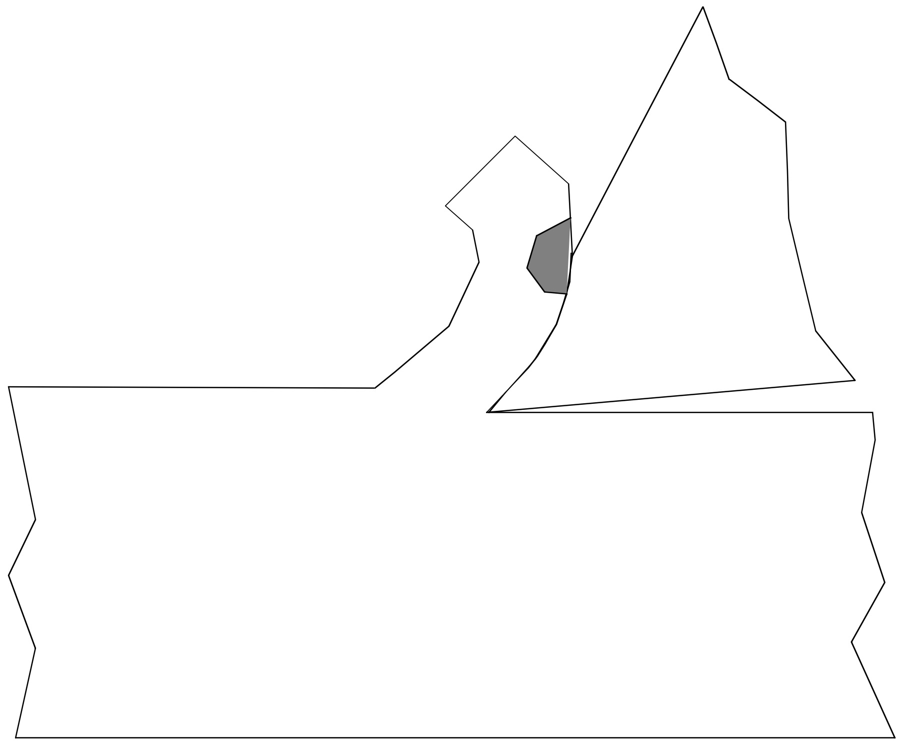
A: Chips are discontinuous, cutting is smooth

B: Built up edge leaves deposits, and increases roughness

C: BUE becomes smaller

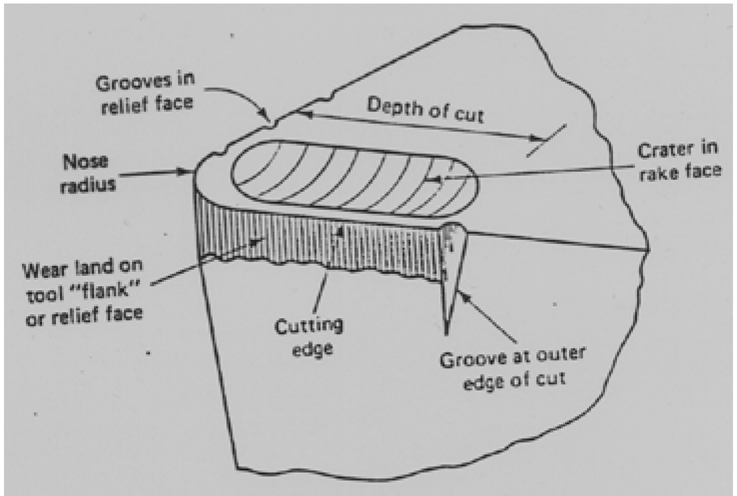


Breaking chips

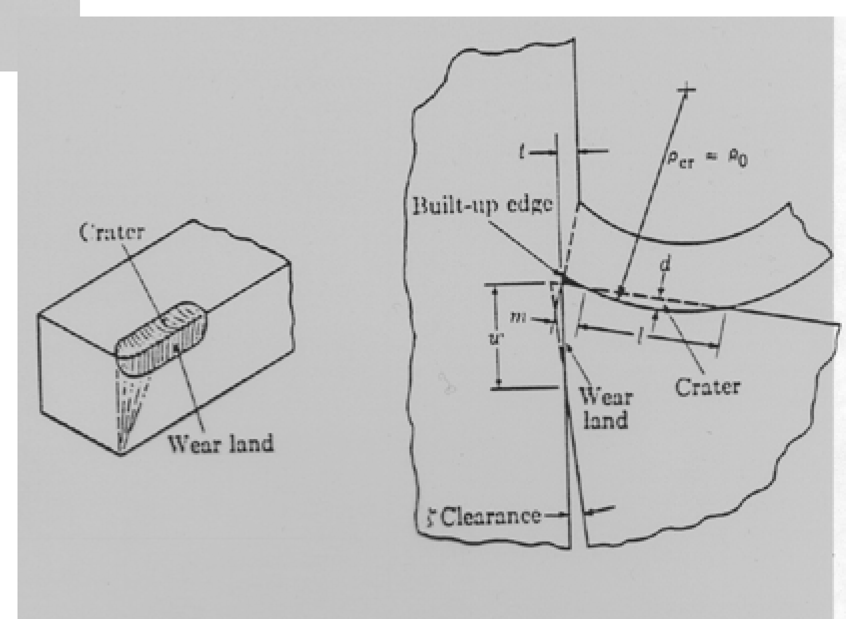


Tool wear criteria

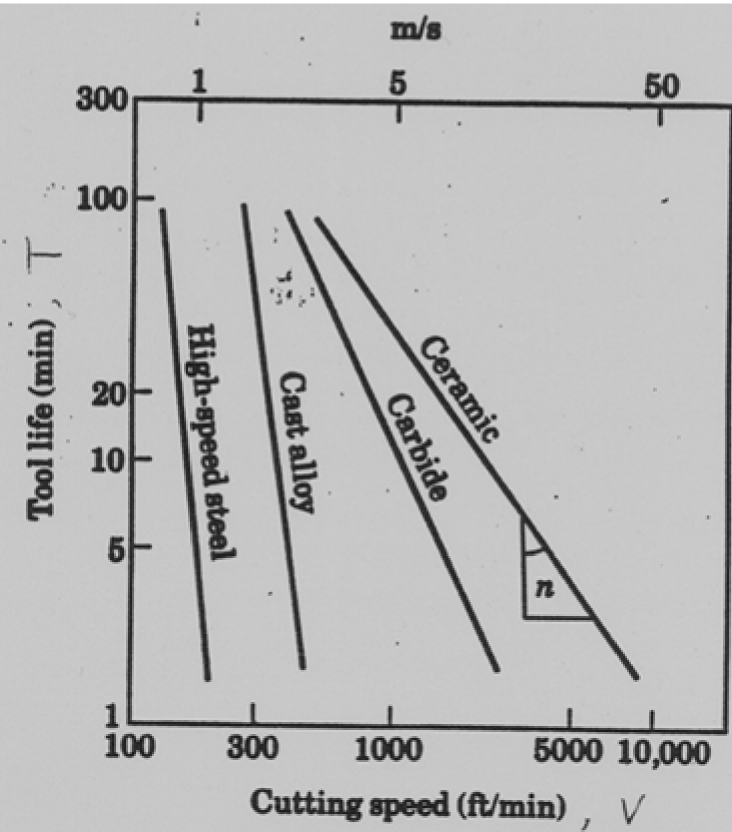
- tool ceases to cut or wear rate tends to infinity
- wear land size: finishing ? roughing ?
- surface finish
- cutting force increase


Grooves in relief face
Depth of cut
Nose radius
Crater in rake face
Wear land on tool "flank" or relief face
Cutting edge
Groove at outer edge of cut

a)


Crater
Wear land
Built-up edge
Crater
Wear land
Clearance

b)



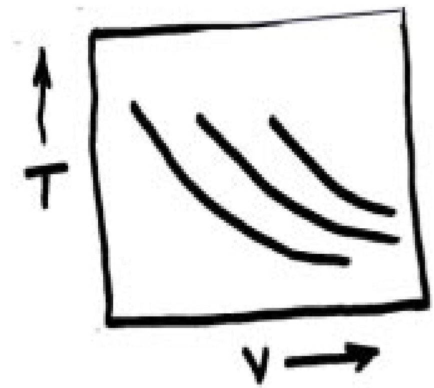
Taylor Tool Life Eq.

$$VT^n = C$$

Taylor Tool Life

$$VT^n = C$$

$$T \propto \frac{1}{V^{\frac{1}{n}}}$$



The coefficient 'n' varies from:

Steels		Ceramics
0.1	→	0.7

Since $\frac{1}{n} > 1$,

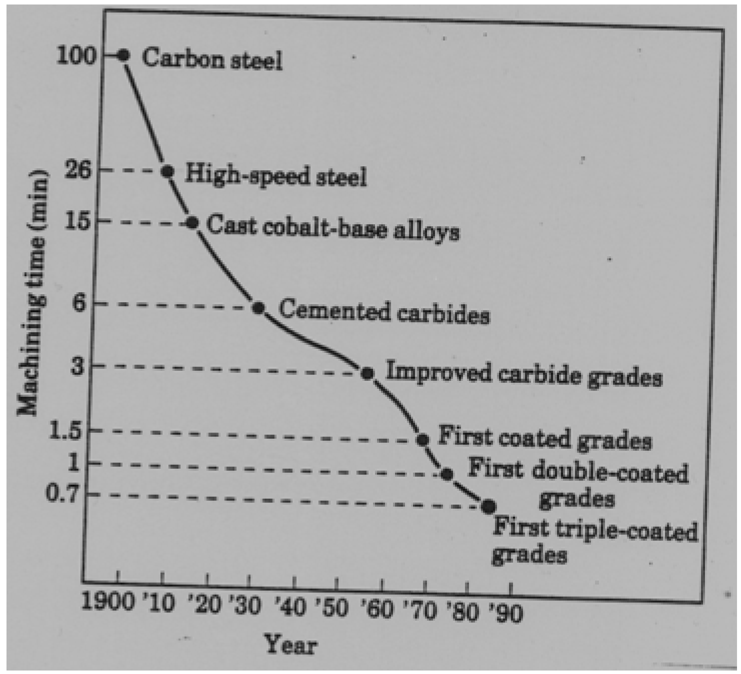
n ↑ → less sensitive to speed

Tool Material Requirement

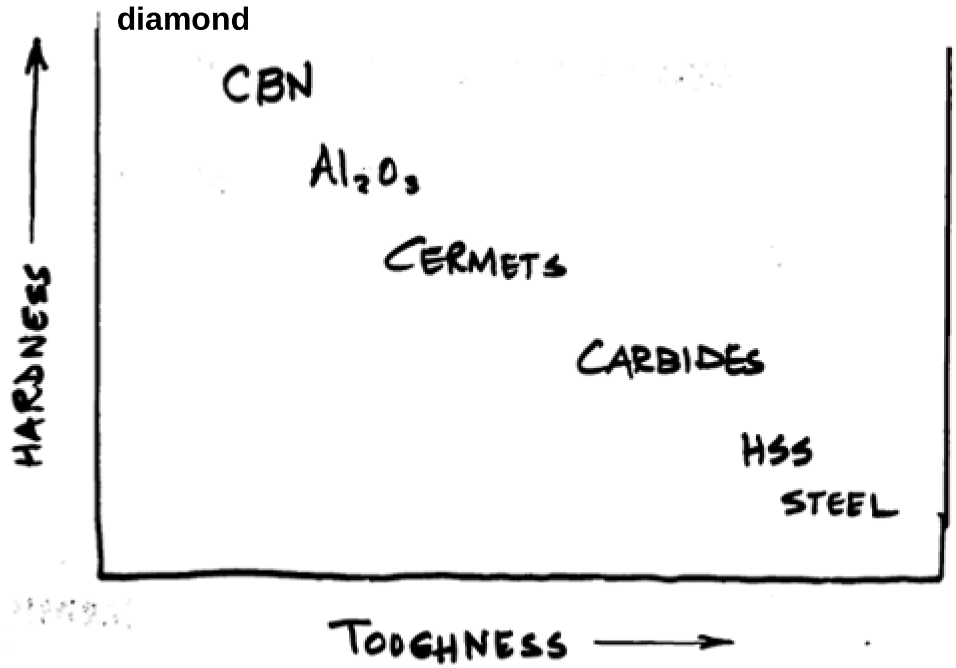
- hard at operating temperatures
- tough
- low wear rate
- easy to form, grind or sharpen
- chemically inert

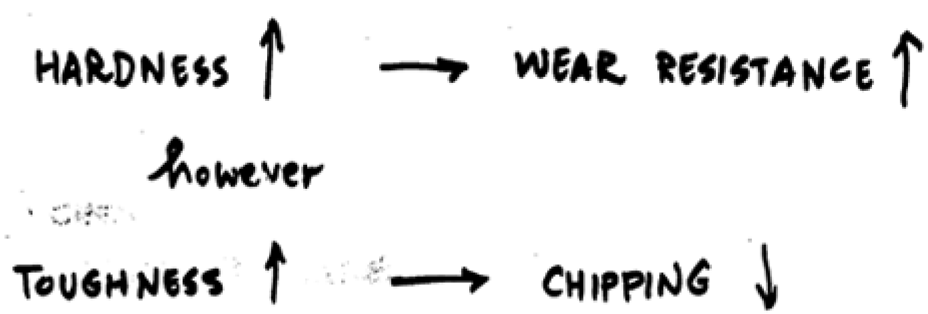
Tool Materials

- high carbon steels
- high carbon alloy steels
- high-speed steels
- cast alloys
- cemented carbide
- ceramics
- diamond
- coated tooling


100
26
15
6
3
1.5
1
0.7
Machining time (min)
Carbon steel
High-speed steel
Cast cobalt-base alloys
Cemented carbides
Improved carbide grades
First coated grades
First double-coated grades
First triple-coated grades
1900 '10 '20 '30 '40 '50 '60 '70 '80 '90
Year

Material Trade-offs

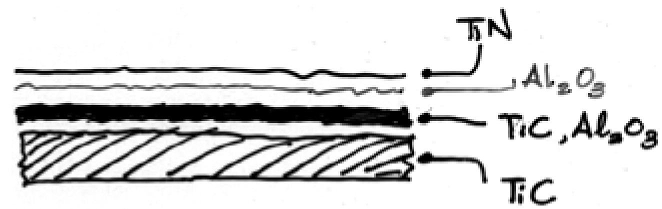




Coated Tools

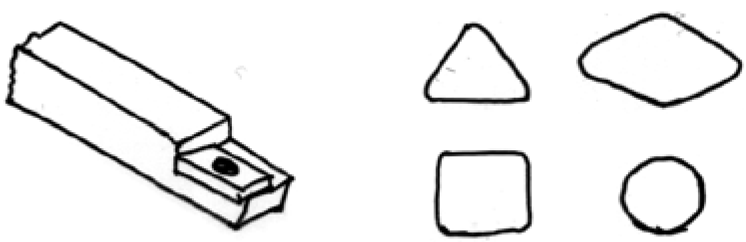
Layers of one material on the other

- combined advantage
- cheaper



INSERTS

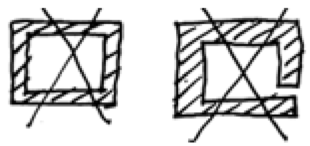
- cheaper to replace
- cheaper to make
- indexable
- standardizable



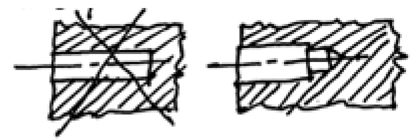
DFM for Machining

1. Geometric Compatibility

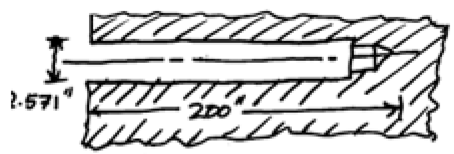
no hollows or overhangs

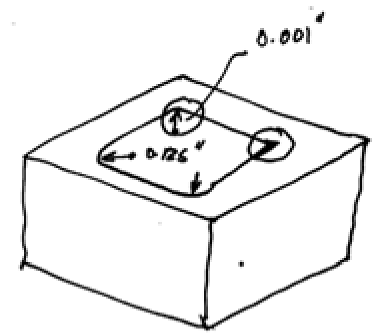


hole must correspond to tool forms

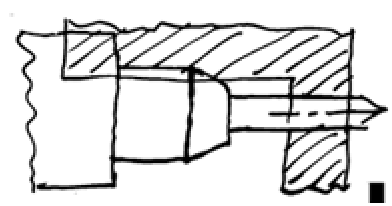


2. Dimensional Compatibility





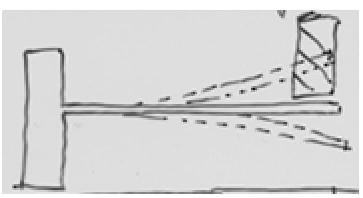
- use standard dimension 2.5” instead of 2.57”
- make sure the tool is long enough!
- use reasonable internal radii
- make sure you have tool access!

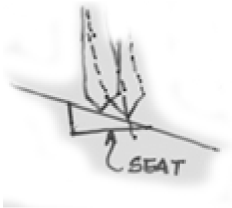


DFM for Machining . . .

3. Process physics related limitations:

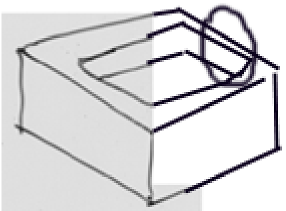
- dont make long, skinny sections that might vibrate





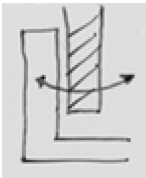
- thin walls will break!

- never drill inclined faces



- deep pockets in hard materials

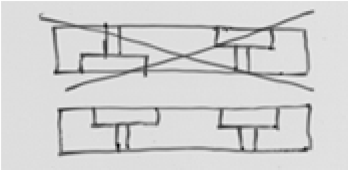
will cause tool vibrations



DFM for Machining . . .

4. Setup and Fixturing

- minimize setups
- use datums
- use similar hole dimensions
- dont over-tolerance



- think fixtures