Making a Part That Can Be Made

NX Workshop 2

Kyle Twarog

Modification is Inevitable

- Ensure that the critical geometry of your files can be readily modified without changing their solution or having to ‘remake’ the file
  - Use meaningful user expressions whenever possible
  - When assigning constraints, think ahead!
- Assign meaningful datums to your files
  - NEVER ‘guess’ what a datum should be! Think it out!
- Think out your parts before making them. NX is not a sketchbook, don’t use it as one!

Use of Design Accelerators

- Design accelerators are built-in features such as threading, hole, and face-blending tools that can allow for common or complicated tasks to be completed quickly
- The Good
  - Allows for uniformity in the completion of these tasks
  - Fast and easy to use
- The Bad
  - Often limited in terms of compatible standards, especially for threading tools
- The Ugly
  - May not allow for easy modification
  - Must be thought-out ahead of time

Understanding the Purpose of a File

- Virtual Proof of Concept
  - Used for simulation?
  - Used for ‘board room’ discussion?
- Actionable Model
  - Used for simulation?
  - Used for manual manufacturing?
  - Used for CNC or similar manufacturing?
- Customer Portal or UI
  - Detailed rendering?
  - ‘Icon’ or fast render?

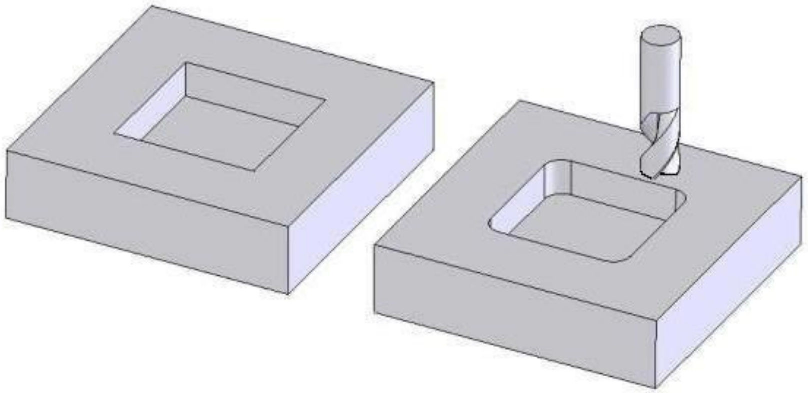
Transmitting Your Intent

- Think through the process of constructing your file, and do so in a logical manor
  - Construct features using the absolute datum first, as well as any sub-features
  - Define additional datum objects as needed and immediately define their child features
- Clean up your files
  - Do not leave frozen, hidden, or suppressed features or objects in your files!
- Think of the file tree as being a step-by-step tutorial for others to follow

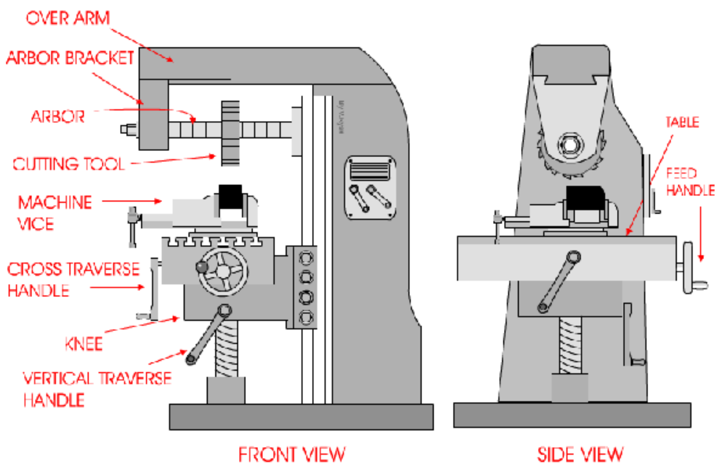
Understand Your Manufacturing Process

- Every manufacturing process has a given set of design constraints and requirements that much be fulfilled
- Three basic types of manufacturing techniques:
  - Conventional Machining
    - Removes material in order to create a feature
  - Additive Manufacturing
    - Adds material in order to create a feature
  - Casting
    - Fills a mold created using the above methods to create features simultaneously

Conventional Machining - Milling

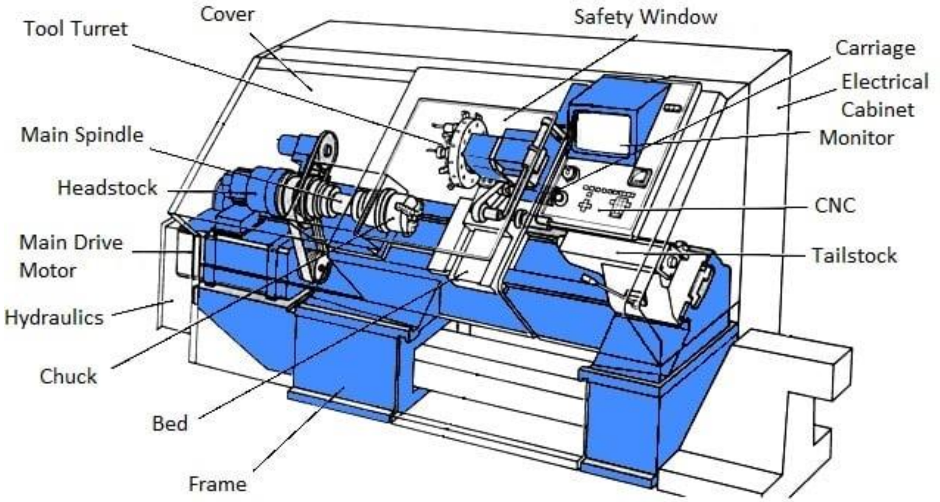


- Uses a spinning bit with cutting surfaces called 'flutes' to shear material from a surface
- Multiple axis combinations
  - 2 axis: 2D geometry
  - 3+ axis: 3D geometry
- Requires that pockets and channels possess radiused corners along the ends of the toolpath
- Requires that the material be mountable in a vise, be bolted to a mounting surface, or be clamped to a mounting surface
- Different milling bits will have additional design constraints depending on their geometry
- This is how most of your extrusions can be manufactured cheaply and quickly



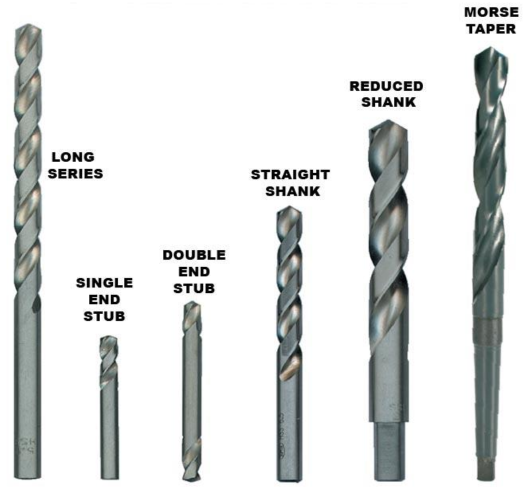
Conventional Machining - Turning

- Uses single cutting surface to shear material from a spinning piece of stock
- Requires that features be continuous along the turning axis
  - This is how most revolve features can be manufactured cheaply and quickly
  - Can also pattern polygons using polygonal turning
- Requires that the material be bolted to a flange or mounted in a vise



Conventional Machining - Boring

- Uses a spinning bit to shear material from a piece of stock along the central axis of the bit to create a hole
- Surface finish and precision of the hole is highly dependent on the type of bit utilized
  - Boring bar vs drill bit
- Mounting requirements are flexible
- The bottom surface of a blind hole is dependent on the geometry of the cutter
- This manufacturing technique is often combined with milling or turning



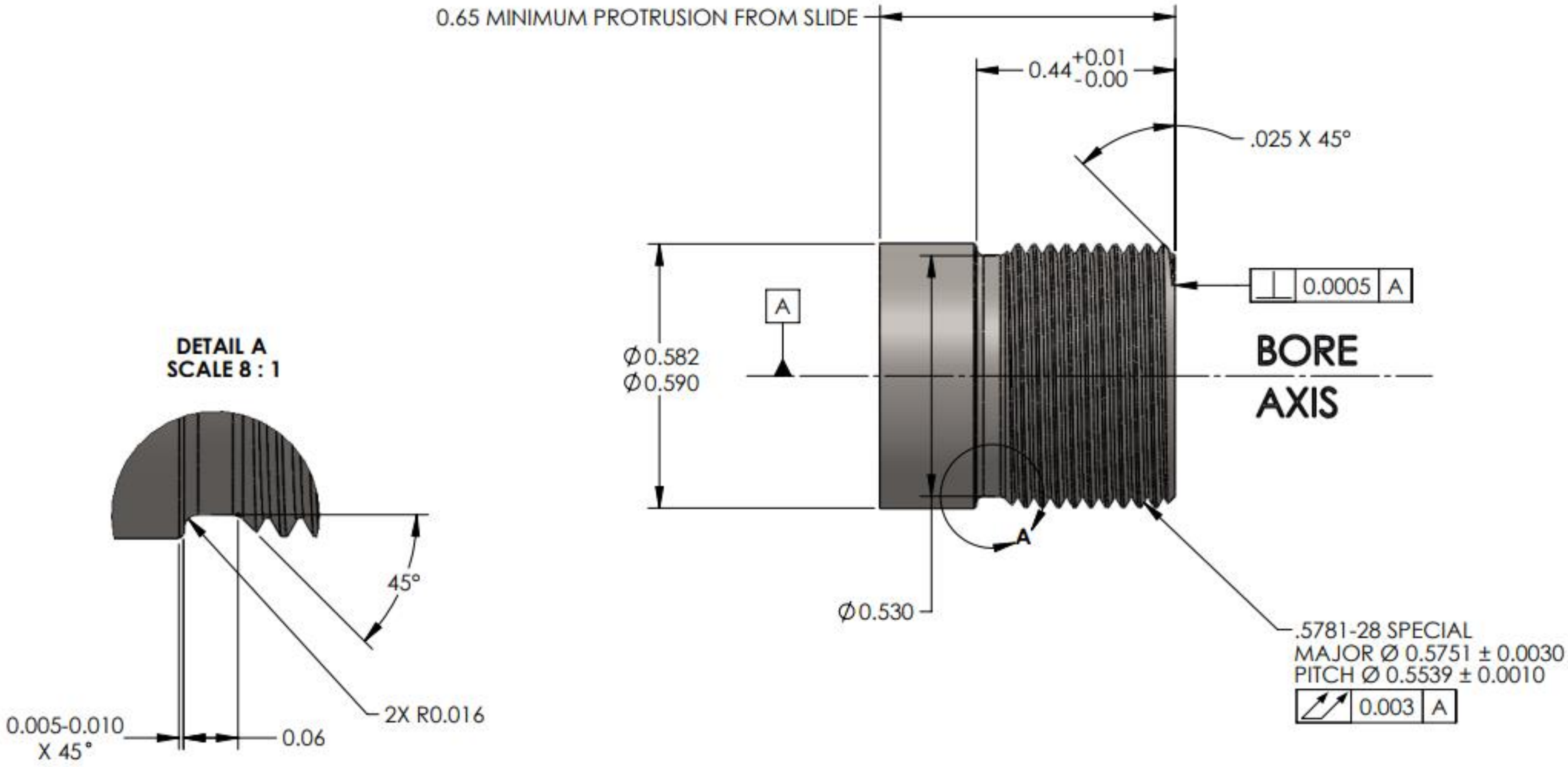
Conventional Machining - Grinding/Polishing

- This technique utilizes the friction between a piece of stock and an abrasive grinding surface to remove material and create a feature
- This method is time consuming and expensive, however it allows for extremely high precision surfaces to be produced
  - Surface uniformity/finish (RA)
  - Flatness/deviance across a linear surface
- This is how most dynamic contact surfaces are finished once their general geometry has been established via other methods
  - Ex. Contact surfaces for gears or rails
- Generally requires that the surface be easily accessible to a flat or cylindrical grinding surface
  - Custom tools are available, but expensive

Conventional Machining - Threading

- Threads are cut either using a specialized turning process or via a specialized cutter depending on specification
  - External threads are cut with a die, internal threads are cut with a tap
- This process can be time consuming, but allows for flexibility in terms of user interaction with a part
- Thread specifications are dictated by established standards. Know what standard you are using before making the part!
- External threads cannot be cut exactly to a boss
  - Thread relief
- Internal threads cannot be cut completely to the end of a blind hole

Conventional Machining - Threading



Credit: Advanced Armament Corp.

Additive Manufacturing – Fused Deposition Modeling

- This technique heats a continuous filament of material to the point of plastic behavior and deposits it on a work surface to generate features. Additional layers of material are deposited as needed.
- Most commonly used with plastics and composites, but more modern machines also use alloys of various types
- This is the least expensive form of AM, however it possesses the worst surface finish, lowest feature resolution, and only forms porous parts.
- Requires that features be ‘larger’ than the resolution of the machine,
- Requires that cantilevered features be ‘small’
  - Some machines do not have this limitation
- Final parts CANNOT be assumed to possess the same material properties as the original filament material!

Additive Manufacturing – Selective Laser Sintering

- Also called Direct Metal Laser Sintering and a few other names
- Applies a thin layer of fine powder to a work surface, then utilizes a laser to sinter specific portions of the powder into solid features. Additional layers are then set and sintered as needed to form the final part.
- Can be utilizes with both plastics and superalloys (Inconel 718)
- Extremely expensive and time consuming and produces parts of similar surface finish to casting, however this method is of higher resolution than FDM and produces non-porous parts
- CANNOT produce cantilevered features
  - Most machines limit ‘roof’ features to 45 degree angles or greater
- Requires that all features be ‘larger’ than the resolution of the machine

Casting

- Investment casting
  - A detailed negative of the desired part is manufactured from a sacrificial material (sand, ceramic) and filled with molten material. The material is then allowed to harden, and the resultant part is collected by destroying the outer mold
  - Relatively high detail for casting
  - Allows for the rapid construction of large, complex parts without extensive welding
- Die casting/Injection Molding
  - A two-part negative mold is formed from metal and filled with pressurized material. That material is allowed to harden, and the resultant part is collected from the mold by separating the two parts of the mold
  - Good surface finish compared to other casting methods
  - Extremely expensive, practical for repeatedly producing identical parts
    - Ex. Legos or engine blocks
  - Produces a defined ridge on the resultant part where the two halves of the mold come together

Casting – General Considerations

- All casting methods produce imperfections and/or unwanted features where the mold is filled
  - Bubbles can create additional imperfections and weak points if your part is not designed with casting in mind
- Cast surfaces are generally unacceptable for use in dynamic contact surfaces or precision mounting surfaces
- Cast steel parts are generally soft, and require heat treating to remove internal stresses and harden the part’s surface
- The construction of casting molds is extremely expensive and time consuming. Keep the purpose of your file in mind!

General Manufacturing Considerations

- What is your tolerance for each feature?
  - If you don’t know, think it through!
  - Remember, tolerances stack!
- How much material will it take to make this part?
- How long will it take to make this part?
- Can I simply buy this part off the shelf?

Remember: Engineering is not the science of perfection, it is the science of “good enough”.

Choosing a Material

There are six common categories of materials used in mechanical design:

- Ferric Metals
- Aluminum
- Exotic Metals/Alloys
- Red Metals
- Plastics and Polymers
- Ceramics

Wood is also often used in mountings and in static frames, however its mechanical properties are not trivial to test or tabulate.

Likewise composites are used commonly in the transportation industry, however that category is far to broad to talk about in these brief terms.

Ex. Carbon fiber composites

Ferric Metals

This category of metals includes any and all metal recopies that use an iron base. The most common of these are:

- Iron
  - Iron is usually used for large cast parts, as it is easier to work with in liquid form than a steel
  - Iron is not as hard as low carbon steel, however it can possess similar yield and ultimate strength values
  - Iron is also used as a bearing material as it possess a relatively low coefficient of friction against steel parts and conducts heat better than steel
- Mild or Low Carbon Steel
  - This category is made up of steels containing between 0.05-0.5% carbon depending on the reference utilized
  - These steels are harder than iron and are usually less expensive, however they take more time to machine
  - These steels are used for general mechanical parts and static assemblies
  - Ex. A36 or 1018 steel

Ferric Metals Cont.

- Regular/High Carbon Steel
  - These steels contain 0.5-2.0% carbon and are both harder and stronger than mild steels
  - These steels are often extremely stiff and generally can be heat treated for additional hardness and strength
  - These steels are used for dynamic parts such as shafts and rails
  - Ex. 1095 or AR500
- Alloy Steel
  - These steels contain varying amounts of carbon as well as large amounts of other ‘alloying’ metals such as Bismuth, Manganese, Nickel, and Titanium
  - These steels are expensive relative to their simpler counterparts, but can be tailored to meet very specific performance criteria

Ferric Metals Cont.

- Stainless Steel
  - These are alloy steels that contain a minimum of 10.5% chromium and at most 1.2% carbon
  - These steels range widely in terms of strength and toughness, however they are exclusively more resistant to corrosion than non-stainless steels
  - When looking for a given level of strength, stainless steel will generally be more expensive than carbon steel
  - Stainless steels have a tendency to gall in both machining processes and mechanical components, making them poor choices for dynamic components such as rails or shafts without heat treating
    - This also makes them time consuming and expensive to machine
  - Ex. 304 and AUS-8
- Tool Steel
  - These are carbon and alloy steels that are specifically blended for their hardness and strength
  - These steels are generally extremely strong, however they are also extremely brittle. This makes them a poor choice for mechanical components subjected to any kind of impact loading
  - These steels are extremely expensive, and extremely time difficult to machine
  - Ex. D2 and O1

Aluminum

- Aluminum is the most common material used in modern mechanical design. It is lighter and generally tougher than steel, however it is not as hard nor as strong.
  - For reference aluminum still has the density of granite, so be sure to optimize your parts if weight is a concern!
- Aluminum is moderately expensive, however it is easy to machine resulting in generally low part costs
  - Aluminum can also be cast much in the same way as a mild steel or iron
- Aluminum is a good choice for structural components, light-duty mechanical components, and heat sinks
- Aluminum is not a good choice for mechanical components that experience heavy frictional loads, nor for components that must cope with abrasion
- DO NOT USE ALUMINUM WHEN YOU SHOULD BE USING STEEL!
- Ex. 6061 and 7075

Exotic Metals/Alloys

There are many ‘exotic’ metals used by mechanical engineers. Two of the more interesting ones are:

- Titanium
  - Titanium is an extremely strong, extremely light metal that can be used when the strength of steel and the density of aluminum is required
    - See: the SR71
  - Titanium is extraordinarily expensive and extremely difficult to machine, so it should be considered something of a last resort
- ‘Superalloys’
  - These are special, usually proprietary, metal blends that are very strong, perform well under repeated thermal stress, and exhibit a high resistance to corrosion
  - These materials are often used in additive manufacturing processes and in highly specific components such as turbine blades
  - These metals are extremely expensive
  - Ex. Inconel 718 and Waspaloy

Red Metals

This category of materials includes copper, brass, and bronze.

- Copper
  - Copper is a soft, workable metal valued for its thermal and electrical conductivity
  - Due to its expense, copper should be chosen exclusively as a conductor
- Brass
  - Brass is an alloy of copper and zinc, generally being harder and stronger than copper
  - Even though it is more expensive then aluminum, brass is extremely easy to machine quickly allowing it to be used for rapid prototyping or in applications requiring extreme amounts of corrosion resistance
- Bronze
  - Bronze is an alloy of copper and tin, and is generally the hardest and strongest of the red metals
  - Bronze is also more expensive than aluminum, however it possess an extremely low coefficient of friction when paired with most other metals, making it the primary material used in bearings

These materials are also able to be drawn and extruded easily, allowing them to be formed into wires and pipes.

Plastics/Polymers

This is a very wide category containing various synthetic materials. Some common examples include:

- ABS
  - Acrylonitrile butadiene styrene (ABS) is moderately strong relative to other plastics and is extremely tough
  - ABS can easily be additively manufactured and is a good choice for low strength, low cost components that will cope with impact loads
- Nylon
  - Nylon is a family of thermoplastics that are known for their abrasion resistance
- Acetal Resin
  - Polyoxymethylene, or acetal, is a family of thermoplastics known for their machinability, hardness, and low coefficient of friction
  - A proprietary blend known as Delrin is commonly used in bearings that do not require high thermal loads

There are many other materials in common use such as acrylics, polycarbonates, and polyesters. Before choosing a plastic, do some reading to ensure it is the proper choice!

Ceramics

Ceramics are crystalline materials formed from metallic or non-metallic powders. These materials are generally very specialized.

Non-metallic ceramics are known as glass.

Ceramics generally:

- Are extremely brittle
- Possess low ultimate strength values
- Cope well with repeated, high-intensity thermal loads
- Are extremely hard
- Are extremely difficult to machine

Due to these qualities, ceramics are often used in non-impact bearing surfaces (such as those of a turbine) and as the working surfaces of breaking systems.