



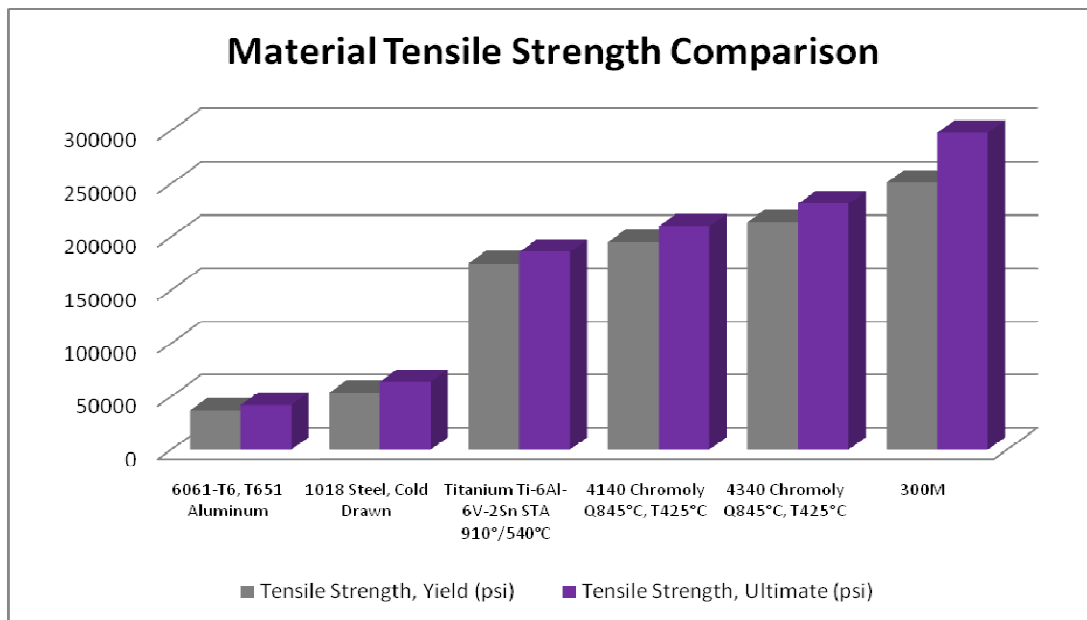
## 68RFE Input Shaft Design



### Material

ATS billet input shafts are engineered for the long haul. A combination of superior materials, processing and design make them the best input shaft available. ATS input shafts start with the highest grade, American made, vacuum melted 300M chromoly steel.

What is 300M? 300M is the common trade name for a type of ultra-high strength steel. 300M is a modified version of AISI 4340 chromoly with silicon, vanadium and slightly greater carbon and molybdenum content than 4340. This alloying with proper processing can achieve yield strengths of 246,000-280,000 psi and ultimate strengths above 300,000 psi. What does this mean? The following chart shows some common materials, special alloys and super alloys.



As shown above, high strength chromoly steels are stronger than the best titanium alloys. For comparison, AISI 4140 steel is a very common form of chromoly steel used in racing and applications requiring strength and durability. AISI 4140 can only be found with yield strengths up to about 170,000-210,000 psi and common low carbon steels as low as 50,000 psi. 300M is an ideal material for an input shaft not only because of its superior strength but very good toughness, fatigue strength and ductility. These factors mean it is not only incredibly strong, it can handle abuse. That is why 300M is used for aircraft landing gear.

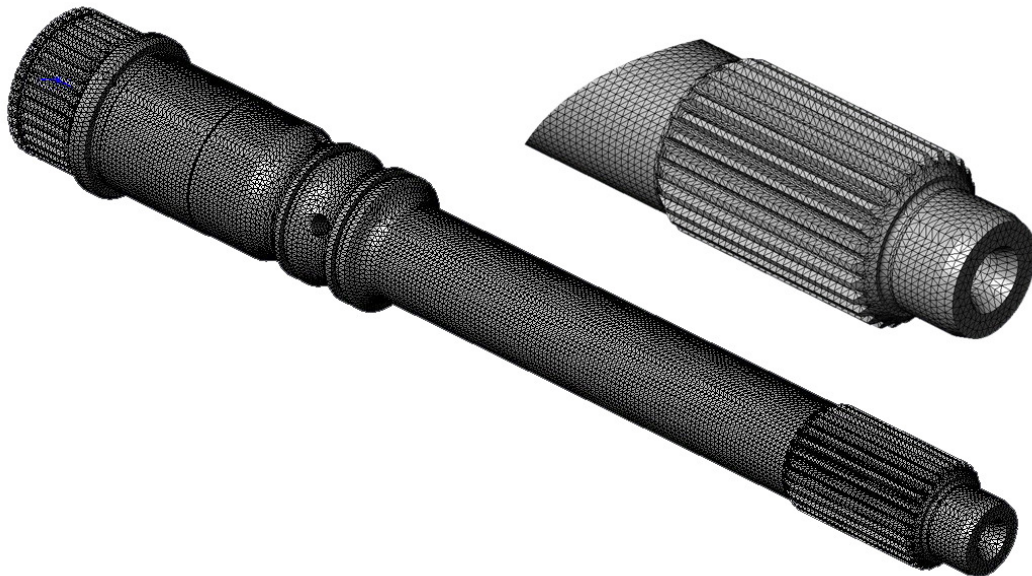
While more expensive than imported versions, American made 300M is held to stringent production standards and often exhibits better strength and durability.

## Processing

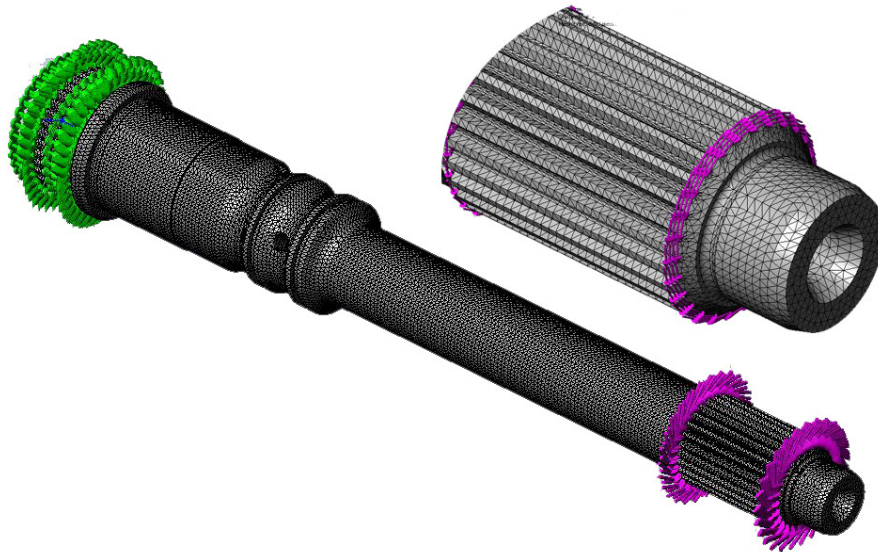
All ATS input shafts start as a solid billet of material. "Billet" is an overused term in the aftermarket. All billet means is that the part is machined from raw round or rectangular stock (versus a forging or casting). A billet shaft can be made from 300M, 4340, 1018 or any number of other types of weaker materials, which is why specifying the type of material is so important. After ATS billet input shafts are machined, they are splined and heat treated. This is where many manufacturers stop the production process. ATS shafts are then finish machined to ensure proper fitment and improved fatigue resistance. Poor surface finish increases the potential for surface cracks in the material (explained in "Shaft Failure Mechanics").

## Design

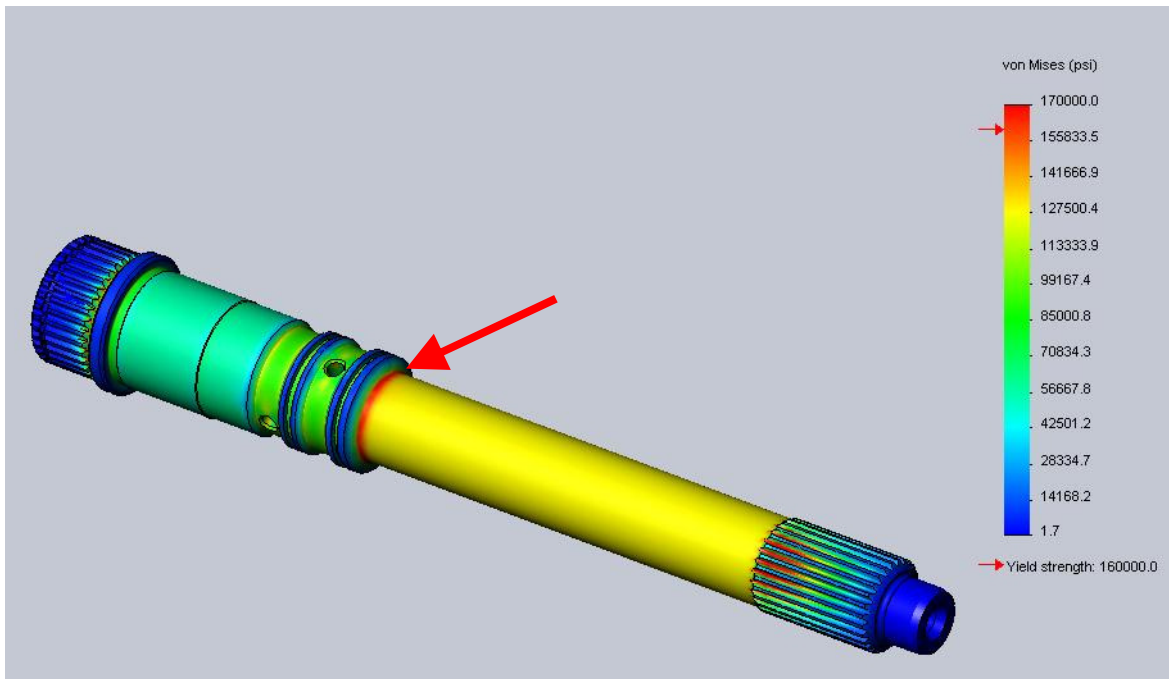
When it comes to design, our engineers have spent countless hours optimizing the input shaft design. This effort produced the strongest and most durable input shaft on the market for the 68RFE. All designs start in the computer utilizing CAD software. Our engineers model each feature and apply material data based on the material selected for the analysis. The process for strength testing is called finite element analysis. The shaft is partitioned into a manageable number of elements for analysis (typically between 400,000 and 1.5 million depending on complexity and geometry). To get these elements, a "mesh" is applied to the part (shown below).



Once the part is meshed, loads and fixtures are applied. In this case, an evenly distributed torque is applied to the contact surfaces of each spline.

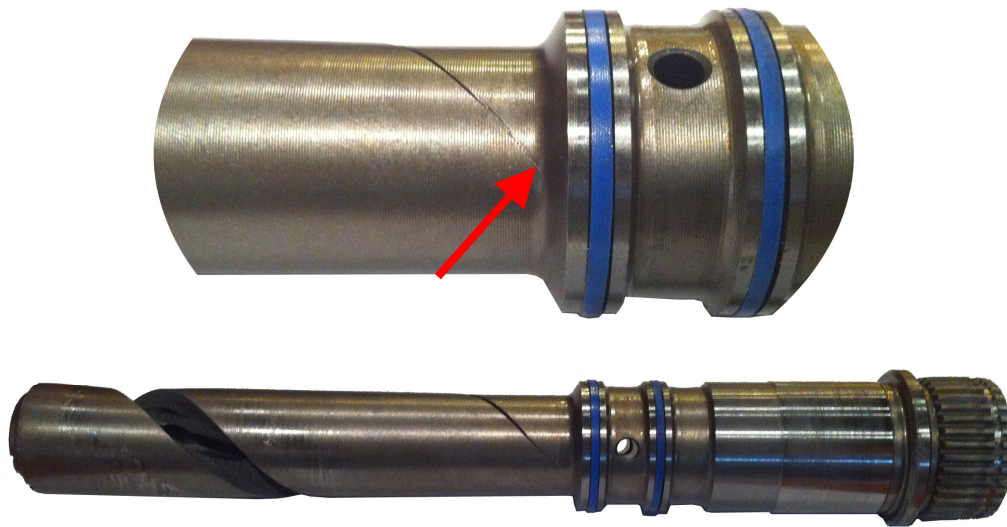


Once meshed and loads applied, the analysis can be run. Below is an example of a factory input shaft tested at 1400 ft-lbs of torque.

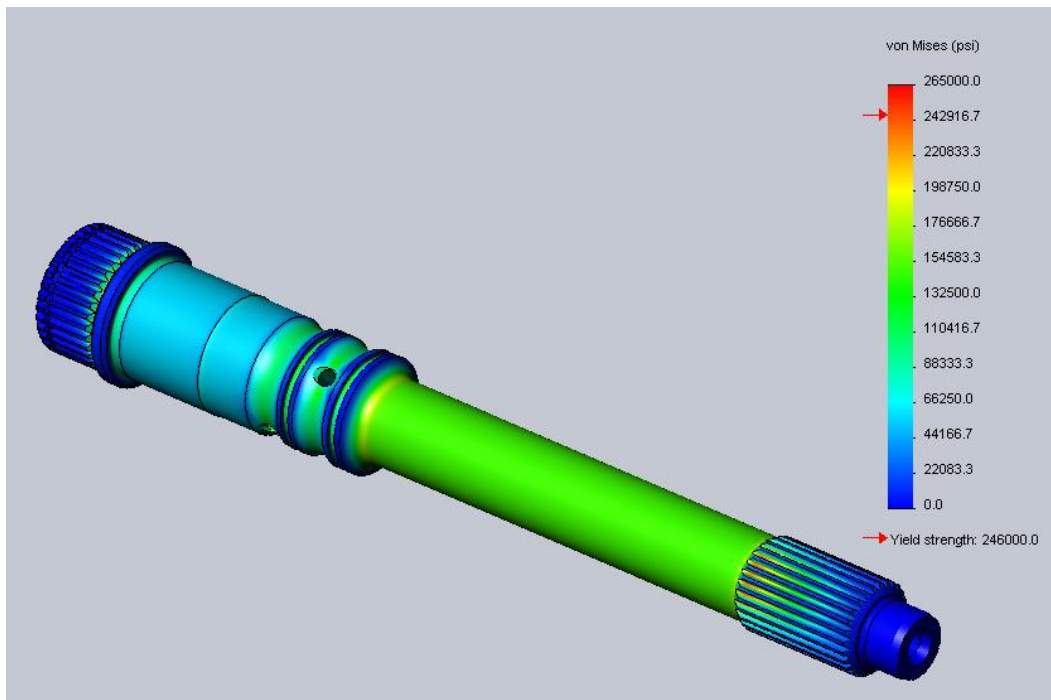


The small red arrow in the legend indicates the color code for the yield point of the material (where the material will deform and not return to its initial shape). As seen in the plot, there is a large red band around the input shaft near the sealing ring lands (mesh and loading graphics were omitted for clarity).

This type of stress concentration leads to spiral fractures like the one shown below. Note how the crack initiates at the root of the radius.



The new ATS billet input shaft addresses this issue through superior design. Below is the analysis of the ATS billet input shaft design tested at the same mesh size and 1400 ft-lbs of torque.



While some stress is concentrated through the length of the shaft, it is all well below the yield point and is distributed more evenly through the length of the shaft.

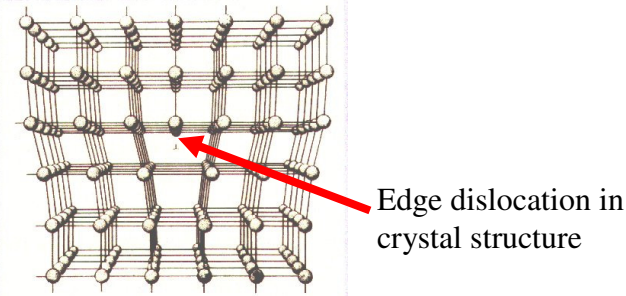
With the optimized geometry, the shaft has not only high torque load capacity but impact load resistance and drastically increased fatigue life. For a more detailed discussion of why and how shafts fail, please read "Shaft Failure Mechanics" below.

## Shaft Failure Mechanics (abridged version)

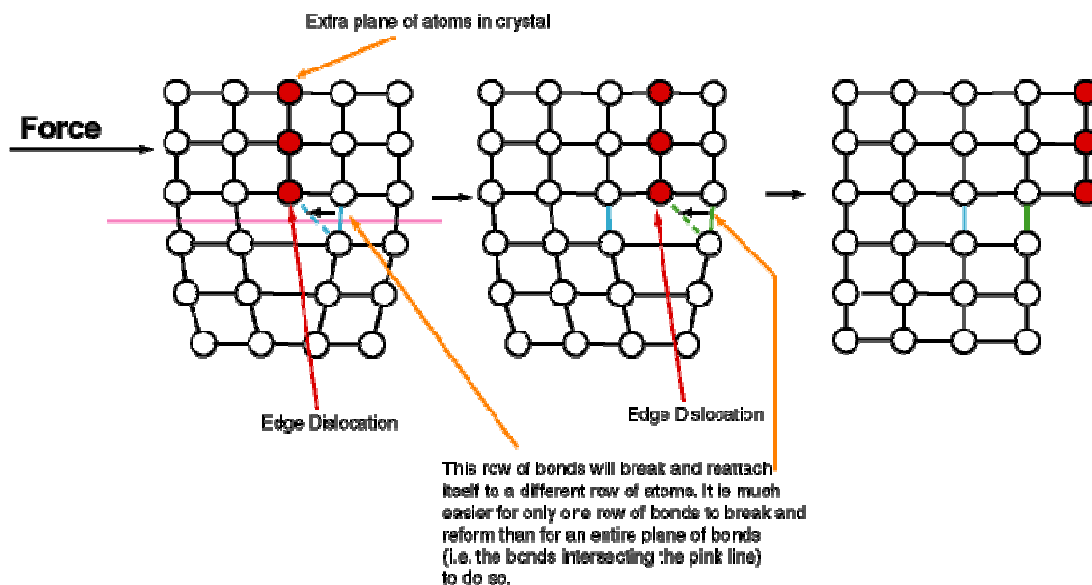
Shafts fail in several ways and from various causes. The engineering goal is to optimize the design to nearly eliminate these failures. Load magnitude, number of times applied and rate of application all factor into the strength of an input shaft.

One of the simplest and most straight forward causes of failure is extremely high torque loads, stressing a shaft above its breaking point. The second is much more complex and is called fatigue. Fatigue occurs when a material is subjected to repeated loading and unloading. Fatigue life (the number of cycles before failure) is affected by many factors including the type of loading, the size of the part, surface finish, operating environment temperature and how corrosive the operating environment. The shape of the structure will significantly affect the fatigue life; square or sharp features will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions are therefore extremely important to increase the fatigue strength of a structure.

If the loads are above a certain threshold (typically lower than the yield strength), microscopic cracks begin to form at the surface. Eventually a crack will reach a critical size, and the structure will suddenly fracture. Microscopic cracks, or microcracks start as dislocations in the lattice structure of a material. Dislocations come in many forms, but are essentially areas where a crystal structure is not perfectly due to particle impurities and inclusions. Impurities and inclusions are present in ALL materials. Material processing techniques can reduce their incidence, but never eliminate them entirely. Below is a typical form of dislocation.

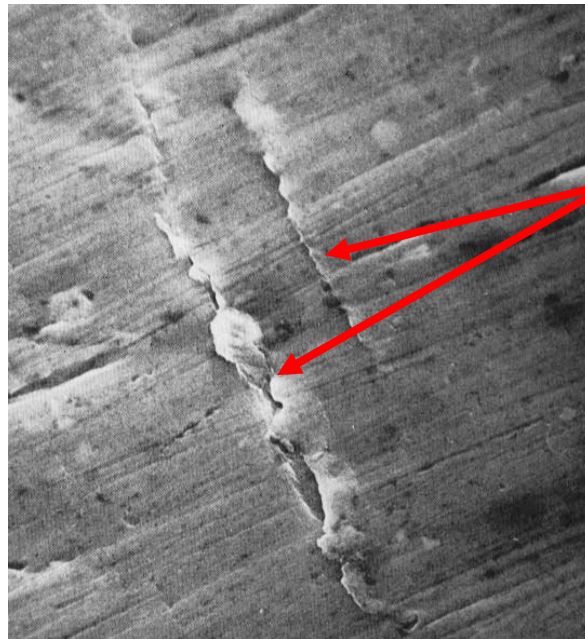


When stressed, the electromagnetic bonds between each atom can jump to a different atom to relieve the stress. These dislocation migrations occur more frequently in higher stress regions.





Notches, splines, transitions, holes, etc...any changes in geometry generate localized stress concentrations (areas of increased stress). As the stress oscillates, local yielding may occur due to the stress concentration, even though the nominal stress in the section is well below the yield strength of the material. Localized plastic yielding causes distortion and creates slip bands (regions of intense deformation due to shear motion) along the crystal boundaries of the material. As the stress cycles, additional slip bands occur and join into microscopic cracks. In the case of an input shaft, the highest stress regions are in areas with transitional geometry and on the outermost diameter of the shaft.



Electron microscope image of microcracks

Once a microcrack is established, the mechanisms of fracture mechanics become operable. The sharp crack creates stress concentrations larger than those of the original defect, and a plastic zone develops at the crack tip each time a tensile stress opens a crack, blunting its tip and reducing the effective stress concentration. The crack grows a small amount. The crack will continue to grow as long as repeated loads are applied to the shaft. When the crack becomes large enough, the part will fracture and fail.

Rate of application is a key factor in the design of our new input shaft (a material phenomenon known as viscoplasticity). When applied quickly, solid materials exhibit fluid-like behavior under load and can deform permanently even if the same static load is not sufficient to bend the part. During a shift where there are a few milliseconds between clutch engagement, the shaft rapidly unloads and reloads causing rapid elastic deformation (high strain rate). Rapid deformation also increases the rate of migration of microcracks.

Understanding strain (twisting in this case) is very important. When a torque load is applied to a shaft, not matter how small the torque or how large the shaft some deformation will occur. The geometry of the shaft will determine the location and magnitude of deformation.

This is why the ATS input shaft diameter less than the major diameter of the splines. The diameter is optimized to be the same strength as the splines so shock loads can be absorbed through the length of the shaft by allowing the shaft to twist slightly (similar to a spring). This twist is below the yield point (where plastic deformation occurs) so after the load is applied, it can return to its original shape. Allowing twist increases the amount of time the shaft has to absorb

the impact energy increasing the life of the shaft by reducing localized yielding and microcrack migration.

This is why typical aftermarket input shafts with the main shaft diameters equal to the outer spline diameters are a poor design. In these designs, the shafts are more rigid than the splines, increasing the localized deformation in the splines. This focuses all the impact energy and stress in the roots of the splines (the splines have to absorb this energy in a matter of milliseconds). This causes extreme permanent deformation in the splines (called plastic deformation). This can be seen when splines are twisted but the rest of the shaft is undamaged. These shafts subsequently fail prematurely and often explosively typically destroying the torque converter and surrounding transmission components.