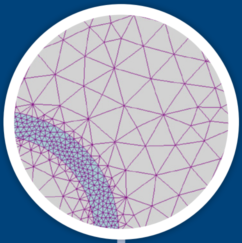
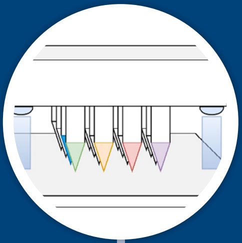
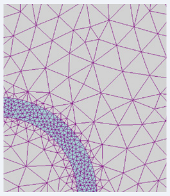
INVESTMENT TO IMPACT
ADVANCED MANUFACTURING

For decades, the U.S. National Science Foundation's investments in advanced manufacturing have led to discoveries and innovations that are making tangible and lasting impacts on the lives of millions of people. These discoveries are helping to transform the future capabilities of 3D printing, computer-aided design and industries such as aerospace, semiconductor and healthcare.

	1950s FINITE ELEMENT ANALYSIS	1970s GEOMETRIC SOLID MODELING	1980s LASER POWDER BED FUSION	1980s BINDER JET PRINTING
NSF INVESTMENTS				
CURRENT IMPACTS				
	DIGITAL TWIN MODELING	COMPUTER-AIDED DESIGN (CAD)	AEROSPACE INDUSTRY MANUFACTURING	3D-PRINTED PPE



NSF INVESTMENT: FINITE ELEMENT ANALYSIS (1950s)
CURRENT IMPACT: DIGITAL TWIN MODELING

In the 1950s, finite element analysis, or FEA, was developed to better understand the complex elastic and structural problems facing civil and aeronautical engineering. Ray Clough, an NSF-supported scientist and a National Medal of Science recipient, is considered to be one of the originators of FEA. **Today, thanks to methodologies built on the foundation of FEA, scientists and engineers have been able to develop digital twin modeling.** A digital twin is a virtual model of a process, product or service. By pairing a virtual model with a physical model, it is possible to analyze and improve systems and product development by testing new capabilities, first on the digital twin and then by replicating this process in the physical twin. **Due to these early investments by NSF, FEA continues to be used as a tool in the production of digital twins by helping to ensure that digital twins are predictive of the real world.**

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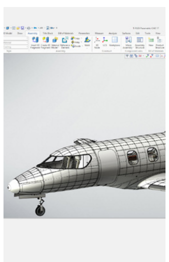

NSF INVESTMENT: COMPUTER-AIDED DESIGN (1970s)
CURRENT IMPACT: GEOMETRIC SOLID MODELING

In the early 1970s, computer-aided design, or CAD, was limited to producing 2D drawings similar to those that were created by hand. Through decades of investing in geometric solid modeling, design capabilities of CAD have become more versatile and sophisticated. One of the first programs for geometric solid modeling was PADL-2, which was developed by NSF-supported researchers, Herbert Voelcker at the University of Rochester and Ari Requicha at the University of Southern California. PADL-2 provided a foundation for the further development of solid modeling packages in the early 1980s that led to a new generation of commercial 3D CAD systems. **Because of NSF investments in early geometric solid modeling, 3D CAD is now the "lingua franca", or standard, of product design and manufacturing. CAD is used today in nearly every physical product development in the world.** Digital manufacturing and digital animation would be impossible without solid modeling. The Boeing 777 was the first airplane to be completely digitally designed using 3D CAD models; this also included the virtual assembly of the plane before the actual plane was put together to make sure all the design elements fit as planned.

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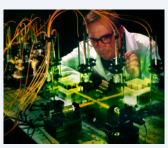
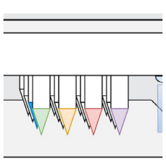
The global 3D CAD software market share is expected to grow from $9.37 billion in 2021 to $10.1 billion in 2022 and $13.54 billion in 2026.

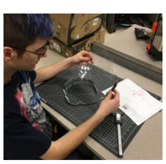


NSF INVESTMENT: LASER POWDER BED FUSION (1980s)
CURRENT IMPACT: AEROSPACE INDUSTRY MANUFACTURING

In the 1980s, NSF supported the development of laser powder bed fusion, also known as selective laser sintering. Carl Deckard and Joe Beaman at The University of Texas at Austin developed a method that used high-powered lasers to fuse small particles of plastic, metal, ceramic or glass into 3D shapes and objects. **Today, this achievement has led to the development of metal additive manufacturing machines, which are used in the aerospace, biomedical and automotive industries.** For example, 3D-printed metal components, such as fuel injectors, are now being manufactured by GE for use in jet engines.

The global 3D printing market is expected to grow from $18.33 billion in 2022 to $83.9 billion by 2029.





NSF INVESTMENT: BINDER JET PRINTING (1980s)
CURRENT IMPACT: 3D-PRINTED PERSONAL PROTECTIVE EQUIPMENT

In the 1980s, Emanuel Sachs and Michael Cima at MIT invented the additive manufacturing process of binder jet printing and were awarded a patent in 1993. Binder jetting fabricates materials by using a print head that sprays liquid binder to attach successive layers of powder. **NSF provided funding support for the development of the binder jetting process in 1989 through the Strategic Manufacturing Initiative.** 3D printing revolutionized manufacturing through an additive process, where products are fabricated by building layer upon layer instead of cutting away from a large block of existing material. The technology had existed for decades, but during the COVID-19 pandemic supply chain challenges made the value of 3D printing clear and, in some cases, urgent. **In the first five months of the pandemic, 3D printers were used to produce personal protective equipment, including 38 million face shield parts.** The global 3D printing market is expected to grow from $18.33 billion in 2022 to $83.9 billion by 2029. As one of the most cost-efficient ways to prototype, 3D printing powers innovation in other sectors. It can even bolster national security; for example, the U.S. Air Force is 3D-printing metal replacement parts.

The U.S. Air Force uses 3D-printing to manufacture metal replacement parts.