Rapid Freeform Sheet Metal Forming: Technology Development and System Verification

DE-EE0005764
Ford, Northwestern Univ, Boeing, MIT, Penn State Erie
Budget Period 1

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Project Objective

- Develop a transformational RApid Freeform sheet metal Forming Technology (RAFFT) to deliver:
  - A sheet metal parts (up to 2.0 m x 1.5 m)
  - Dimensional accuracy (± 1.0 mm) & surface finish (Ra < 30 µm)
  - 3-day art to part total time from receiving CAD model
  - Low per unit variable cost
  - Robust enough to operate in an industrial environment
  - Low energy - utilize a fraction of the energy c.f. conventional stamping

- Current process for sheet metal forming requires costly die design, casting, extensive machining and assembly (Even prototyping and low-volume production)
  - Time-consuming
  - Energy intensive
  - Expensive

- RAFFT is a new type of “Rapid Prototyping” technology for making sheet metal parts that eliminates stamping & forming dies.
Technical Approach

- RAFFT is based on the concept of double-side incremental forming, first developed and proved out by this team.

- The project will bring the technology from TRL4 to TRL6 - demonstrating capability to make automotive and aerospace production parts.

- Design, build and commission RAFFT/F³T Gen II Double Sided Incremental Forming (DSIF) machine.

- Develop
  - Postprocessor, machine & controller simulators
  - Methodology for designing addendums
  - Methods for Quality Inspection, process capability and performance evaluation
  - Models for validating DSIF applications in automotive and aerospace industries

- Integrate tools, methods and processes from NU, Boeing, MIT and Penn State to a single unified platform for making DSIF parts
Technical Approach (cont.)

- **Develop:**
  - Algorithms for DSIF path generation
  - Simulation methodologies for predicting failure modes
  - DSIF process modeling & optimization
  - Design and build a DSIF machine based on kinematotropic machine architecture

- **Material Characterization**
  - **Material performance**
    - Mechanical & Fatigue

- **Determine:**
  - Optimal heat treatment for forming and impact of post thermal treatment
  - Effect and control of lubricants on DSIF

- **Develop efficiency models for DSIF impact on energy, cost & environment**
- **Perform sensitivity analysis, size effect analysis and scale up model for anticipated markets**
- **Validate (above) models for applications in automotive and aerospace industries**

- **Investigate the effect of in-situ thermal processing on material deformation, residual stress & effects on springback during DSIF**
- **Develop CAE model for thermally assisted incremental sheet forming**
- **Develop methodology for localized stiffening incrementally formed shapes.**

- Truncated pyramid for making tensile coupons
- Apply electricity at strategic locations to reduce springback
Transition and Deployment

End Users:

- **Automotive Industry:**
  - Prototype Vehicles
  - Concept Vehicles
  - Vehicle Personalization
  - Low-Volume Production
  - After-Market Part Service

- **Aerospace and Defense:** Low-volume production; in-theater replacement parts.

- **Biomedical:** Customized medical applications (e.g. Cranial plate, ankle support etc.)

- **Appliance:** Prototyping and after-market services

- **Art and Entertainment:** Creative sculptures

Aerospace  
Biomedical  
Automotive
Transition and Deployment

Transition:
- Adopt a “scalable” machine tool architecture and a reconfigurable software system architecture.
- Increase RAFFT technology awareness through demonstrations, media announcements, journal/conference publications, etc.

Deployment & Commercialization Opportunities:
- Create a “RAFFT technology” package and establish a technology licensing framework.
- Make “RAFFT technology” available through third parties.
- Technology adaptation by industry may include:
  - Dedicated systems at OEM and large manufacturing facilities.
  - Service providers to serve occasional or smaller customers.
  - Deployment of smaller units for educational initiations and for technology enthusiasts.
RAFFT has the potential to revolutionize sheet metal prototyping and low-volume production:

- **Energy Efficient and Environment-Friendly**: eliminate extensive energy consumption associated with casting and machining forming dies. No wasteful by-products.
- **Ultra-Low Cost and Fast Delivery Time**: eliminate cost and time associated with die engineering, construction and tryout.
- Preliminary estimates (MIT) suggest RAFFT technology could save $\sim 8.4$ TBtu and $\$12.3$ billion per year in US when fully deployed. Estimates are calculated based upon an analysis of savings in material production, component manufacture and product use.
Project Management & Budget

- **Project Duration**: 42 months (07/2013 – 12/2016)

- **Major Tasks**:
  - Task 1: Energy Management & Environmental Impact Modeling
  - Task 2: Development, Integration and Verification of RAFFT System
  - Task 3: Tool Path Generation Algorithm, Process Modeling and Optimization
  - Task 4: Thermally-assisted Freeform Sheet Metal Forming
  - Task 5: Material Characterization & Performance Validation

- **Key Milestones**:
  - 08/2014: Complete design and engineering of RAFFT machine and control system.
  - 03/2015: Complete the build of the RAFFT hardware.
  - 03/2016: Complete toolpath generation software and integration with RAFFT hardware system.
  - 12/2016: Complete process optimization and technology demonstration with an aluminum hood and a titanium gearbox container. (Achieve TRL6)

### Total Project Budget

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<td>DOE Inv.</td>
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<td><strong>Project Total</strong></td>
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Major Accomplishments Since Last AMO Review:

- Commissioned the RAFFT/F3T Gen II machine at Ingersoll Production Systems on March 26th, 2015.
- Formed truncated pyramids of seven different materials using F3T Gen I machine and sent the panels to Boeing in order to characterize the mechanical properties.
- Developed and implemented a framework for toolpath generation combining various double sided incremental forming strategies.
- Started Developing formability and fracture models for double sided incremental forming
- Enhanced the energy management & environmental impact models, validate by comparing with operations such as superplastic forming, hydro-forming, etc.

Next Major Milestone:

- Make prototype sheet metal parts in less than 3 days from receiving a CAD model while maintaining a surface profile tolerance of +/- 1 mm by March 2016.