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Purdue Applied Research Institute

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Hypersonic Advanced Manufacturing Test Capability

establishing advanced manufacturing innovation center for key national security breakthroughs

Funding through OSD Manufacturing Science & Technology Program in partnership with NSWC Crane NSTXL
S^2MARTS Project Number 21-13


AM Equipment Provider
GE Additive
Lead Systems Integration
LOCKHEED MARTIN
Dynetics
BOEING
DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA
PARI
HAMTC
DESIGN → BUILD → JOIN → TEST
Materials
GE Additive
GE Edison Works
*MOLYWORKS MATERIALS CORPORATION
* CompuTherm FOR MATERIALS DESIGN
Propulsion
AEROJET ROCKETDYNE
GE Edison Works
*innoveering inspire | innovate | deliver
* HYPERCOMP, INC. Leader in High Performance Computing
*Represents small companies

Objectives

Reduce time and cost for next generation prototypes in support of secure hypersonics manufacturing R&D

Co-located facilities for design of components and system integration, additive manufacturing of components and joining of sub-assemblies, and thermo-mechanical and wind tunnel testing of hypersonic sub-systems.

- *Ameliorate problems of RDT&E hypersonic technology transfer via vertical integration and strong industrial partnerships (providing necessary requirements and environments to ensure an applicable solution).*
- *Address key warfighter challenges through advancements in high temperature materials and unique additive manufacturing (AM) prototype equipment, via an exclusive partnership with GE Additive and co-location of personnel. AM has direct applicability to improve weapon systems via quantifiable benefits in the PESS (Performance; Environment; Size, weight, and power (SWaP); and Schedule) metrics.*

Hypersonic Advanced Manufacturing Testing Capability

Advancing Hypersonic vehicle development through manufacturing breakthroughs in support of government stakeholders

High Level Scope of Work

Design

Flow & Design optimization of multi-material systems

- Model Based Engineering Workflow

Build

Additive Manufacturing of disparate material systems

- Customized Production & Qualification Tools

Join

Joining of multi-material systems and components

- Joining of CMCs, C-C, metal alloys

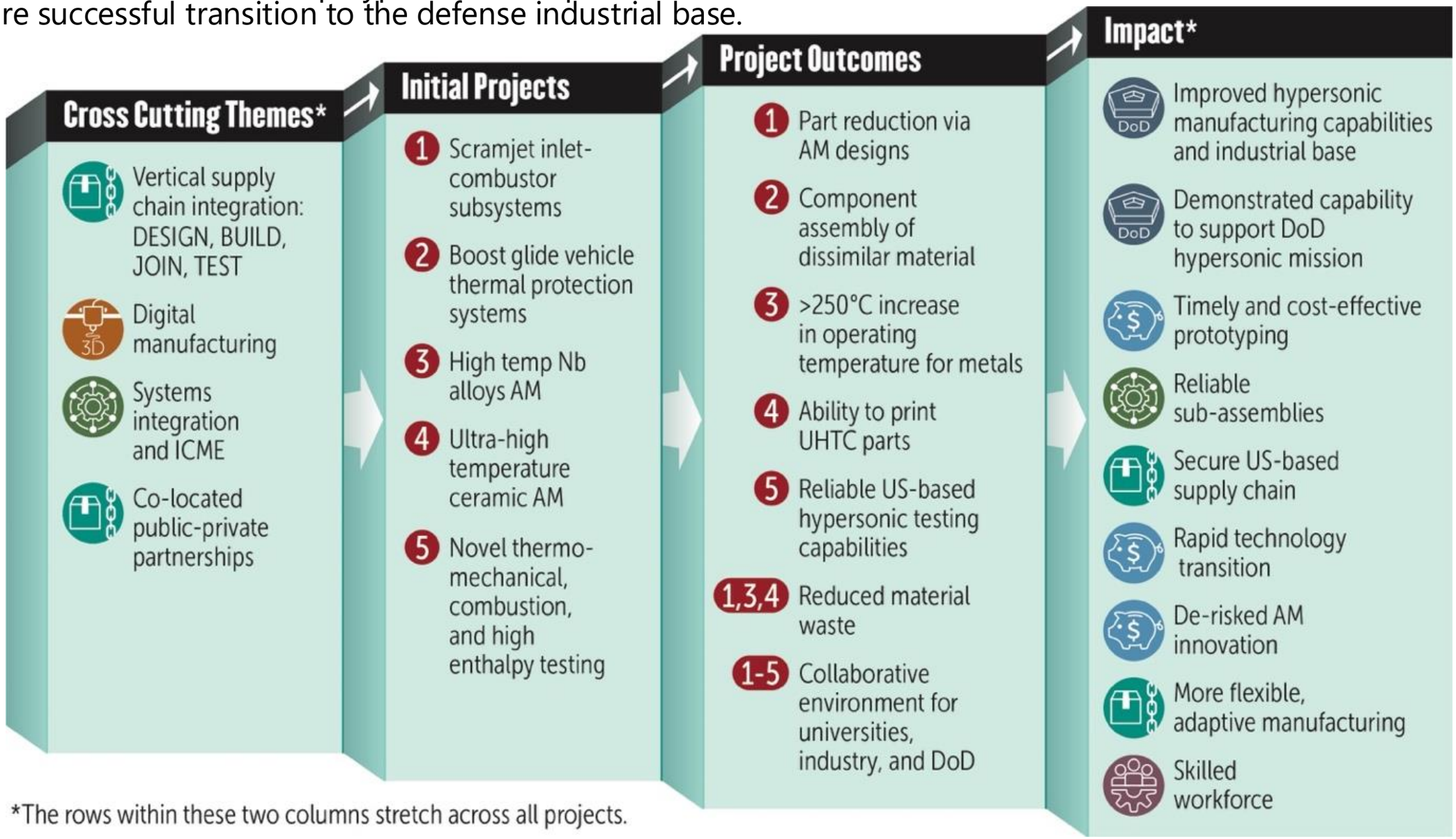
Test

Sub-assembly performance testing

- Thermo-mechanical testing
- Wind tunnel testing

Outcomes and Impact of HAMTC

Reduce time/cost to develop hypersonic components/sub-assemblies and ensure successful transition to the defense industrial base.



Key Technology Partnerships

- Given the breadth of hypersonics integration and joining multiple components, HAMTC provides a means to co-locate and collaborate with industrial supply chain during engineering manufacturing development.
- HAMTC help transitions comprehensive solutions for hypersonic platforms, DoD acquisition programs, and industrial supply chain.

Initial Projects

1. Part reduction through additive manufacturing of scramjet inlet-combustor subsystems
2. Critical joining technologies for thermal protection systems in boost glide vehicles
3. Additive manufacturing of Nb-base alloys
4. Additive manufacturing of ultra-high temperature ceramics (UHTCs)
5. Leverage and utilize unique testing capabilities for hypersonic applications to establish vertical integration, including leveraging unique thermo-mechanical, combustion, high enthalpy, and wind tunnel testing

Project 1: Part Reduction through Additive Manufacturing of Scramjet Inlet-Combustor Subsystems

Objective:

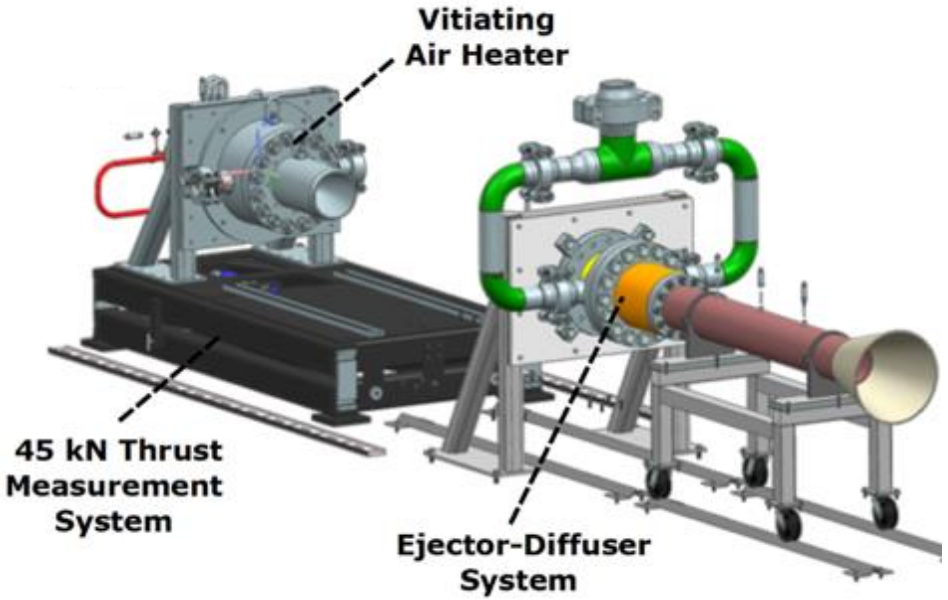
More efficient designs and part-count reductions for scramjets are afforded by AM. Opportunities for improved performance and efficiencies by moving to ceramic inlet.

Project Tasks:

- Redesign for part count reduction, including flow characteristics and structural analysis
- Integrated dataflow through model-based feature information network
- Develop unique digital light projection printer and ceramic AM strategies
- Printing ceramic inlet and metal combustor at scale
- Testing using combustion rig, including laser diagnosis along hot flow path, at scale

Challenges:

- Improving quality and reducing variability in AM parts
- Printing ceramic components at scale
- Mechanical fastener of dissimilar materials
- Interconnectivity and interoperability of engineering data workflows



Project 2: Critical Joining Technologies for Thermal Protection Systems in Boost Glide Vehicles

Dynetics innoveering inspire | innovate | deliver

GE Edison Works

Objective:

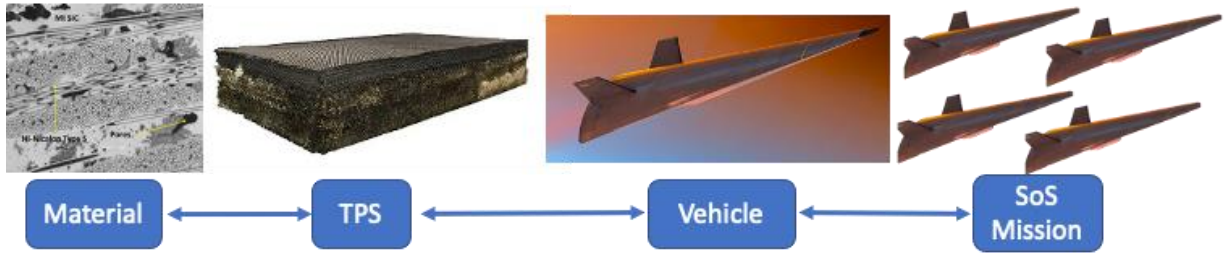
Thermal protection systems (TPS) is crucial to hypersonic flight. Critical joining technologies are necessary to integrate multiple materials with dissimilar coefficient thermal expansion (CTE) behavior into TPS sub-assemblies.

Project Tasks:

- Develop unique mechanical joining and chemical bonding strategies for joining dissimilar materials, including C/C, CMC, metal, and RF window materials
- Material and structural models to identify trade studies with joint design variables
- Integrated digital twin connects joining innovations to mission-level survivability
- Thermomechanical and high enthalpy testing of joints across temperatures of interest

Challenges:

- Vehicle designs require mating two different materials, although CTE differences cause internal stresses that may lead to cracking
- A reliable and durable TPS across operating temperatures, that is affordable
- Difficult to assess system's trade-offs between material scale and overall mission requirements



Systems approach to decisions at multiple levels.

Project 3: Additive Manufacturing of Nb-base Alloys

LOCKHEED MARTIN · MOLYWORKS MATERIALS CORPORATION · AEROJET ROCKETDYNE · CompuTherm FOR MATERIALS DESIGN · GE Additive

Objective:

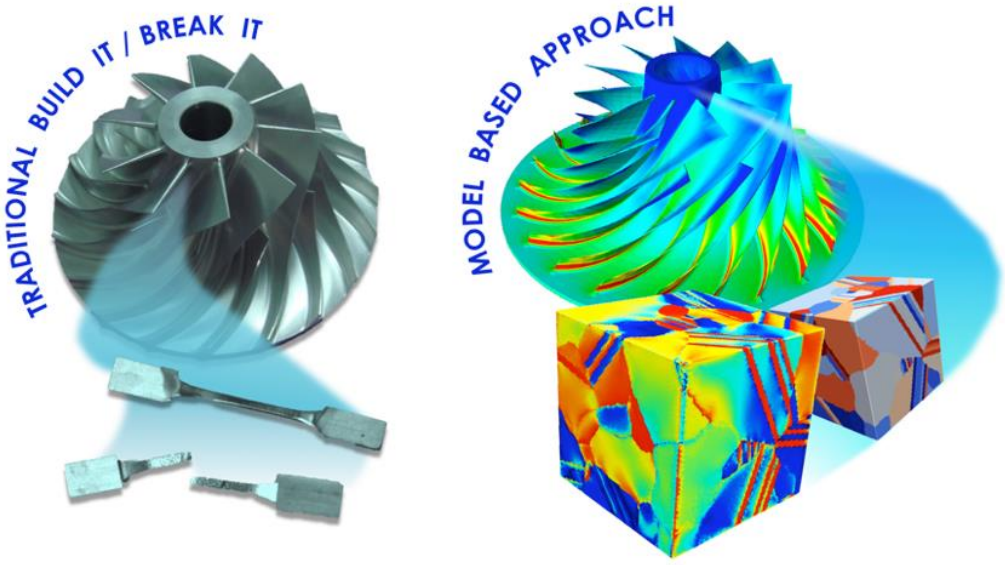
Hypersonics vehicles require materials for use at high temperatures with high thermal conductivities. A tailored composition, AM processing route, and coating solution are developed for a unique Nb alloy based on hypersonic requirements.

Challenges:

- Ni is limited in use to <2000 °F
- Nb is highly reactive and difficult to process
- Limited Nb development activities since the 1960s and commercial solutions
- Broad composition space for new alloy development and Nb requires a coating solution

Project Tasks:

- Via material modeling of the thermodynamics and kinetics, identify compositions of interest
- Produce feedstock and conduct manufacturing trials
- Down-select to one alloy and perform AM parameter optimization
- Develop and apply coating solution
- Perform thermomechanical, oxidation, and high enthalpy testing



Project 4: Additive Manufacturing of Ultra-High Temperature Ceramics (UHTCs)

GE Additive

Objective:

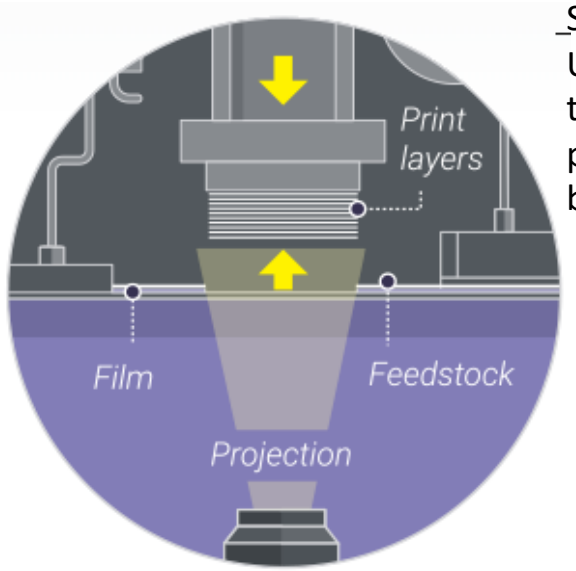
Recognized need for specialty high temperature materials in hypersonic systems. In this project, a large build volume, prototype ceramic printer and associated ceramic slurry feedstock for UHTCs are developed to address complex hypersonic requirements at scale.

Challenges:

- Difficult to manufacture ceramics to net shape at scale, including high production rates, surface qualities, precision, and feature accuracy
- DLP relies on tape casting with slurries of ceramic powder and UV curable resins
- UHTCs are dark in color (high index of refraction), which pose difficulties in curing strategies

Project Tasks:

- Design and construct ceramic printer at scale, using digital light projection (DLP)
- Develop UHTC slurry strategies for UHTC powders
- Identify process parameters, burnout, and sintering to produce high quality parts
- Perform characterization and thermomechanical testing



_Slurry is tape cast onto a transparent film. UV light source projected onto film, curing the resin and forming the 2D slice of the 3D part; process repeated followed by binder burnout and sintering

Images Courtesy of Admatec

Project 5: Leveraging Unique Thermo-Mechanical, Combustion, High Enthalpy, and Wind Tunnel Testing

Objective:

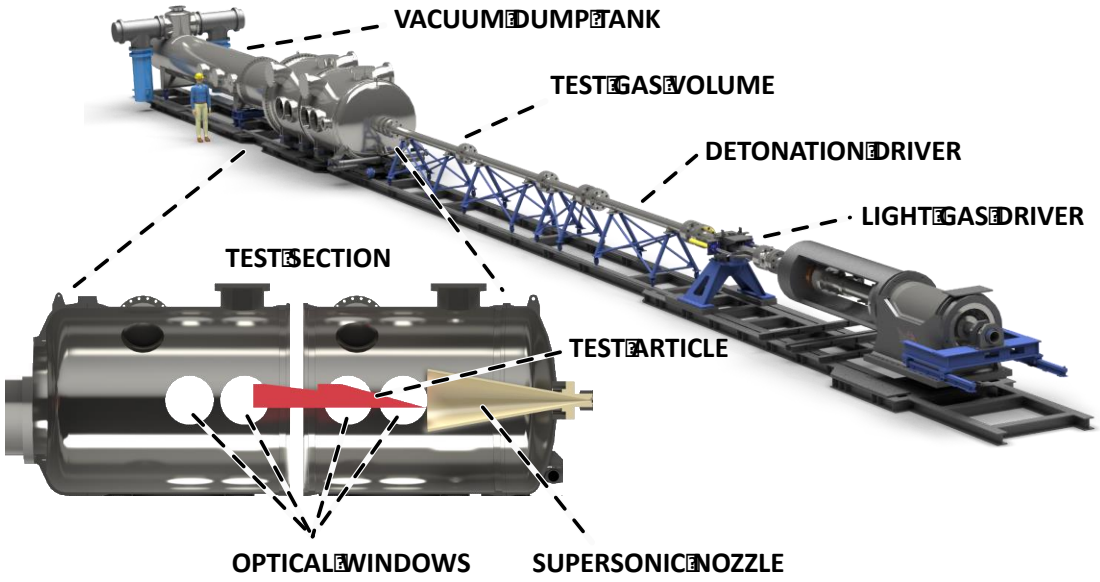
HAMTC will leverage unique, vertically integrated set of testing capabilities to provide a collaborative environment amongst the defense industrial base and federal laboratories to increase efficiency across the prototype's lifecycle.

Project Tasks:

- Utilize thermomechanical test capabilities for metals, ceramics, and composites at temperatures relevant to hypersonic flight
- Develop plasma torch, combined with mechanical loading, to mimic hypersonic environmental testing
- Develop standard data package for different AM modalities, joining, simulations, and testing
- Improve instrumentation and diagnostic capabilities for combustion & high enthalpy tests

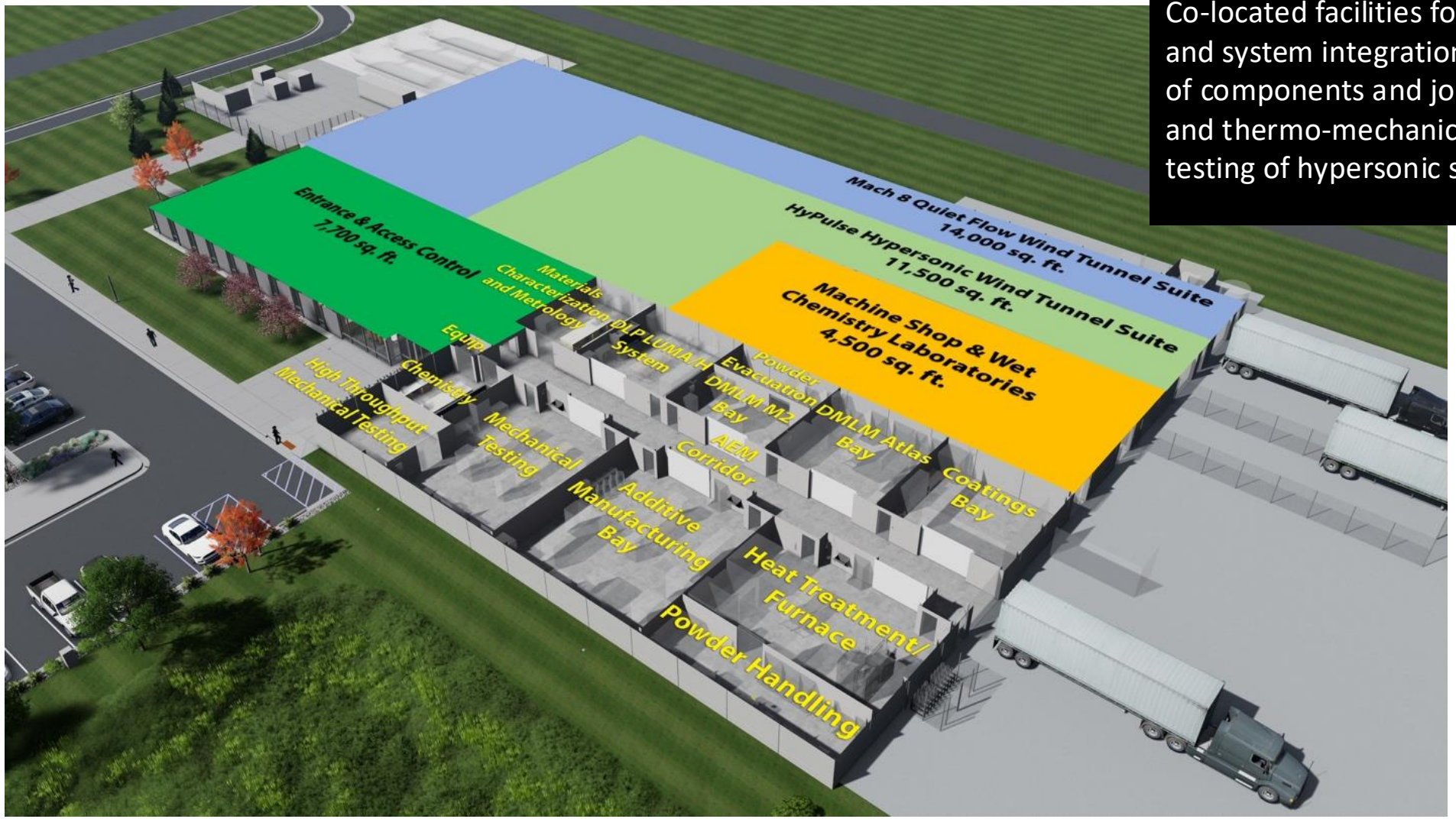
Challenges:

- Current hypersonic testing capabilities and infrastructure in the U.S. is limiting the advancement of hypersonic weapons
- Difficulty obtaining mechanical testing data in hypersonic temperatures and environments
- No standard format for AM data files
- Difficult obtaining experimental validation for multi-physics models at relevant flow conditions



Hypersonics and Applied Research Facility

Physical Center to support secure hypersonics manufacturing R&D



Co-located facilities for design of components and system integration, additive manufacturing of components and joining of sub-assemblies, and thermo-mechanical and wind tunnel testing of hypersonic sub-systems.

HAMTC instrumentation:

- Unique additive manufacturing equipment
- Joining and coating stations
- Furnaces and post processing
- State of the art characterization and metrology
- Wide range of novel thermo-mechanical testing
- Adjacent to Mach 8 and Hypulse testing
- Connectivity to equipment on Purdue's campus and synchrotron based characterization