DISCRETE ELEMENT ROUGHNESS MODELING FOR DESIGN OPTIMIZATION OF ADDITIVELY AND CONVENTIONALLY MANUFACTURED INTERNAL TURBINE COOLING PASSAGES

ROBERT F. KUNZ[1], MICHAEL P. KINZEL[2], DAVID R. HANSON[3], EDWARD W. REUTZEL[3], JASON E. TOWN[3], KAREN A. THOLE[1]
THE PENNSYLVANIA STATE UNIVERSITY
[1]DEPARTMENT OF MECHANICAL ENGINEERING, [2]DEPARTMENT OF AEROSPACE ENGINEERING, [3]APPLIED RESEARCH LABORATORY

STEPHEN T. MCCLAIN, LESLEY M. WRIGHT
BAYLOR UNIVERSITY
MECHANICAL ENGINEERING DEPARTMENT

DOUGLAS C. HOFER
GENERAL ELECTRIC GLOBAL RESEARCH

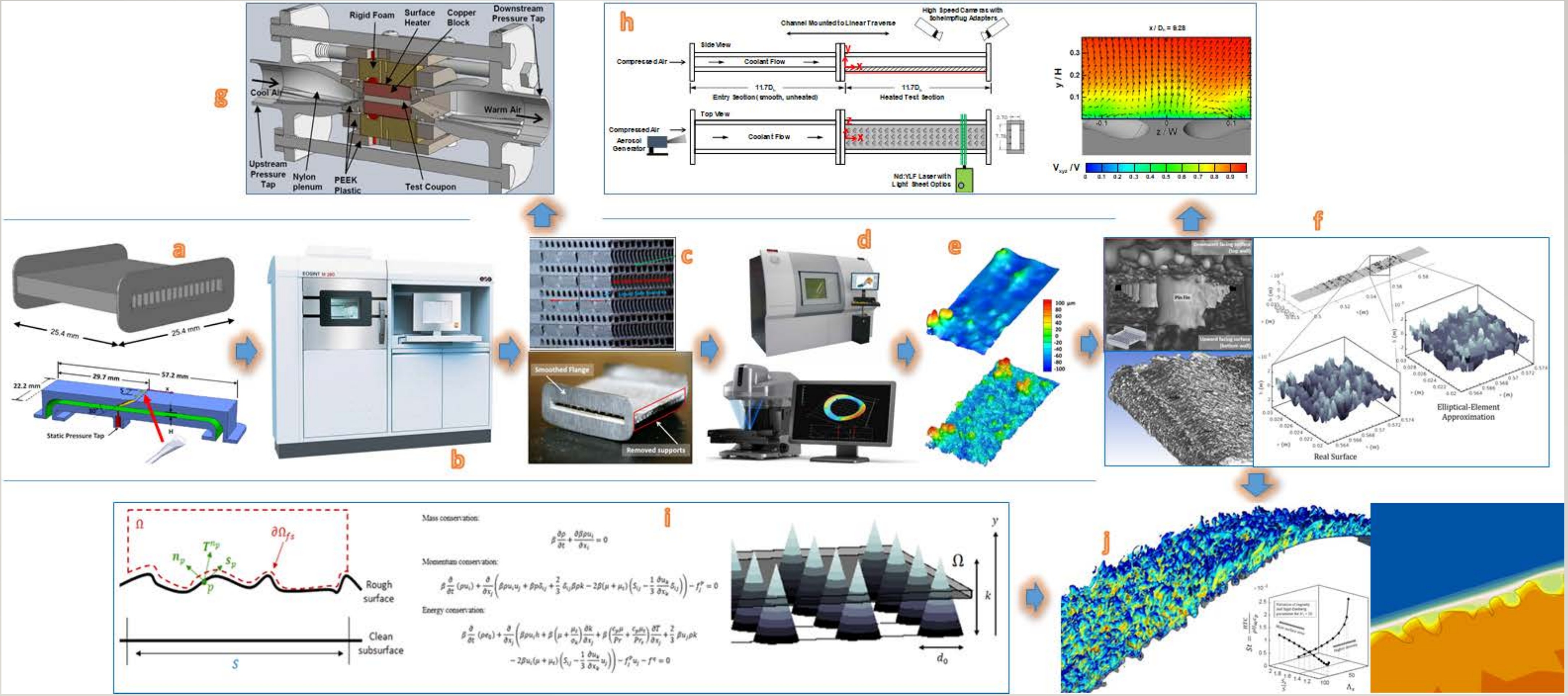
CONTENTS

- Background
- Technical approach
- Project objectives
- Project structure
- Project schedule
- Project budget
- Project Management Plan, Risk Management

BACKGROUND

- Metal additive manufacturing enabling gas turbine designers are able to explore internal turbine passage cooling schemes not manufacturable using current methods
- Potential significant gains in turbine operating temperature and durability ➔ *transformational*
- Can only harness opportunity if we mature thermal design tools
  - Accommodate the very complex "roughness field" that invariably characterizes these engineered flow passages
  - Conventional roughness modeling for CFD predictions of flow field/convective heat transfer are inadequate
- Accordingly, this project develops Discrete Element Roughness Modeling (DERM), in the context of Large Eddy Simulation (LES) and Reynolds Averaged Navier-Stokes (RANS) methods
  - Necessary and sufficient for mechanistic predictions of additively manufactured turbine cooling scheme configurations
  - DERM also represents a viable design approach for conventionally manufactured internal blade cooling features

TECHNICAL APPROACH



a) Design for AM, b) EOSINT M 280 PBF system , c) Engine Scale Parts, d) CT and OP scanning, e) CT and OP roughness fields, f) Synthesized multi-scale geometries for CFD modeling and geometric up-scale, g) Engine scale heat transfer and pressure drop testing, h) Up-scale local conditions flow and heat transfer testing, i) DERM model development/calibration, j) DNS, LES, RANS validation, application, design optimization.

OBJECTIVES

- Advance CFD methods for accuracy and run time requirements for design and optimization relevant to additively and conventionally manufactured turbine cooling scheme configurations
  - Discrete Element Roughness Modeling (DERM) mechanistic-based model for roughness predictions
  - Context of Large Eddy Simulation (LES) and Reynolds Averaged Navier-Stokes (RANS) methods
- Synthesis of state-of-the technology:
  - CFD modeling and optimization
  - Powdered metal additive manufacturing (AM)
  - Multiscale 3D scanning and attendant roughness field characterization
  - Heat transfer and flow measurements.
- Deliver to OEM turbine blade design community a sufficiently physics rich and validated model set for design of blade cooling passages and cooling holes that are subject to the roughness and tolerancing field inherent to Powder Bed Fusion (PBF) manufacturing of these blades.
  - Straightforwardly implemented within current OEM CFD-based turbine design practice.
  - 3D $\therefore$ far more general in breadth of applicability than Q1D

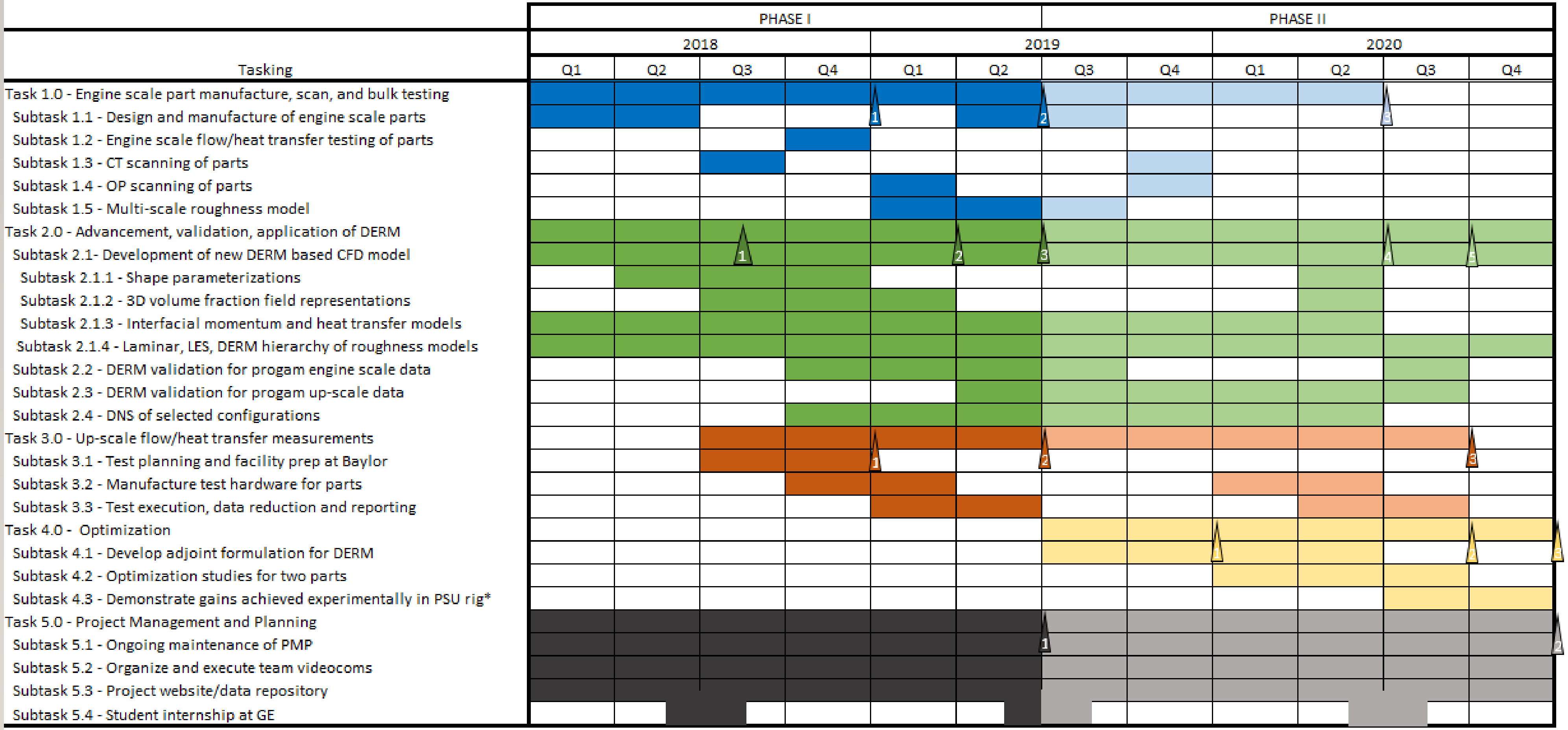
STRUCTURE

- Task 2 - Engine Scale Turbine Cooling Passage Manufacture, Scan, and Bulk Testing
  - Design and manufacture four engine scale parts for inspection and testing
  - Engine scale flow and heat transfer testing of parts
  - Inspection of these parts using CT and OP
  - Develop a synthesized multi-scale geometric roughness model
- Task 3 - Advancement, Validation, Application of DERM
  - Develop a new DERM based CFD model in the context of LES and RANS for representative turbine cooling passage configurations.
    - Development of shape parameterizations based on the various scale and shape "families"
    - 3D volume fraction field representations of PBF roughness fields
    - Scale synthesis and shape parameterizations
    - Interfacial momentum and heat transfer models, using DNS of representative "patches" of measured and synthesized roughness, and laminar and LES models
  - Calibrate and validate DERM model for representative turbine cooling passage configurations using engine scale data and using up-scaled data

STRUCTURE

- Task 4 - Local Conditions Up-Scale Flow/Heat Transfer Experimental Measurements
  - Execute test planning and facility preparation for up-scale testing
  - Manufacture up-scale test hardware
  - Execute test plan
  - Perform data reduction and reporting
- Task 5 - Optimization
  - Develop a continuous adjoint-based shape optimization framework for DERM differential model
  - Execute scheme for full scale PDF manufactured turbine blades
  - Perform optimization studies for two of the parts developed and studied in project, and demonstrate gains achieved computationally

SCHEDULE



*Note per discussion in "Technical Background and Detailed Technical Approach" that Task 4.3 will be carried out only if resources become available through successful attempts to do multiple PBF part builds at once (i.e., enabling a total of 5 parts in 4 builds)

BUDGET

- DOE+Cost Share

Organization	Year 1	Year 2	Year 3	Total
PSU	170,280	146,869	151,081	468,230
Baylor University	71,354	67,964	68,798	208,116
GE		37,197	37,197	74,394
Total	$241,634	$252,030	$257,076	750,740

	Year 1	Year 2	Year 3	Total
• Cost share:	$11,900	$48,747	$90,093	$150,740

PROJECT MANAGEMENT PLAN, RISK MANAGEMENT

- Task1 – Project Management, Planning and Reporting
  - Manage and direct the project in accordance with PMP to meet technical, schedule, budget requirements
  - Coordinate activities to effectively accomplish work
  - Ensure project plans, results, and decisions are documented
  - Ensure project reporting and briefing requirements are satisfied
  - Update PMP as necessary to accurately reflect current status of the project
  - Manage project risks in accordance with risk management methodology delineated in PMP
    - Identify, assess, monitor and mitigate technical uncertainties
    - Identify, assess, monitor and mitigate schedule, budgetary risks associated
    - Presented risk management process during project reviews and Progress Reports