ROUTING AND ACTION
MEMORANDUM

ROUTING

TO: (1) Mathematical Sciences Division (Myers, Joseph)

Report is available for review

(2) Proposal Files Proposal No.: 76403-MA-ST1

DESCRIPTION OF MATERIAL

CONTRACT OR GRANT NUMBER: W911NF-20-P-0002

INSTITUTION: Coreform LLC

PRINCIPAL INVESTIGATOR: Luke Engvall

TYPE REPORT: Monthly Progress Report

DATE RECEIVED: 3/3/20 2:37PM

PERIOD COVERED: 17-Jan-2020 through 16-February-2020

TITLE:

ACTION TAKEN BY DIVISION

(x) Report has been reviewed for technical sufficiency and IS [x] IS NOT [ ] satisfactory.

(x) Material has been given an OPSEC review and it has been determined to be non sensitive and, except for manuscripts and progress reports, suitable for public release.

Approved by SSL\JOSEPH.D.MYERS on 3/4/20 6:55AM

ARO FORM 36-E

REPORT DOCUMENTATION PAGE	Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
03-03-2020	Monthly Progress Report	17-Jan-2020 - 16-Feb-2020

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Automating U-spline fluid-structure model development for mobility applications	
	5b. GRANT NUMBER W911NF-20-P-0002
	5c. PROGRAM ELEMENT NUMBER 665502
6. AUTHORS Luke Engvall	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES	8. PERFORMING ORGANIZATION REPORT NUMBER
Coreform LLC 1427 South 550 East Orem, UT 84097 -0000	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211	ARO
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) 76403-MA-ST1

12. DISTRIBUTION AVAILIBILITY STATEMENT

Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

This report is the second of six monthly reports and details the work performed during the period of performance dated 17-JAN-2019 to 16-FEB-2020. As outlined in Fig. 1, the two primary tasks during this period of performance were to 1) begin to build a 3D U-spline model of a single stage axial turbine, and 2) continue to optimize the CU Boulder CFD code for U-spline based simulations. Work on these tasks has proceeded according to schedule, and the key achievements for each task are detailed in the attachment.

15. SUBJECT TERMS

2nd Monthly Report

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Luke Engvall
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Prescribed by ANSI Std. Z39.18

Report Title

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Monthly Report for POP Ending 16-FEB-2020

Luke Engvall

February 2020

1. Contract and Proposal Number	Contract No.: W911NF20P0002 Proposal No.: A19B-006-0063
2. Contractor's name and address	Corefrom LLC 1427 South 550 East Orem, UT 84097
3. Title of the project	*Automating U-spline fluid-structure model development for mobility applications*
4. Contract performance period	17-DEC-2019 TO 16-JUN-2020
5. Total contract amount	$171,177.55
6. Amount of funds paid by DFAS to date:	$32,696.30
7. Total amount expended/invoiced to date:	$32,696.30
8. Number of employees working on the project	Coreform LLC: 2 CU Boulder: 3
9. Number of new employees placed on contract this month	Coreform LLC: 0 CU Boulder: 0

There is no classified or sensitive information contained within this deliverable.

This report is the second of six monthly reports and details the work performed during the period of performance dated 17-JAN-2019 to 16-FEB-2020. As outlined in Fig. 1, the two primary tasks during this period of performance were to 1) begin to build a 3D U-spline model of a single stage axial turbine, and 2) continue to optimize the CU Boulder CFD code for U-spline based simulations. Work on these tasks has proceeded according to schedule, and the key achievements for each task are detailed below.

				Month					
	Description	Owner	Calendar weeks	1	2	3	4	5	6
Technical Objective 1	Build U-spline benchmark model of the turbine	PI Engvall	21						
Task 1.1	Gather benchmark requirements from the Army	PI Engvall, Sede	1						
Task 1.2	Build 3D U-spline model of the turbine	Hortin	10						
Task 1.3	Fill remaining fluid domain by augmenting the boundary layer U-spline with additional elements	PI Engvall, Thom	10						
Technical Objective 2	Run simulations on benchmark U-spline turbine model in the CU Boulder IGA code	Dr. Evans	14						
Task 2.1	Optimize CU Boulder code for U-spline CFD simulations.	Dr. Evans	8						
Task 2.2	Set up and run a simulation on the three-dimensional turbine	Dr. Evans	6						

Figure 1: Gantt chart highlighting tasks scheduled during this period of performance.

Task 1.2: Build 3D U-spline model of the turbine

During the second period of performance Coreform began constructing a U-spline model of a simple single-stage axial turbine. The first step of this effort was to build a simple CAD model of the turbine, similar to that shown in Fig. 2. DeAnna Gilchrist of CU Boulder provided Coreform with STEP files containing CAD models of representative stator and rotor components, which were loaded into Coreform Trelis (Fig. 3a). Then, Mitch Hortin of Coreform began constructing a CAD model of the fluid domain inside the turbine. The fluid domain was modeled as two annular volumes, one each for the stator blades and the rotor blades[1] (Fig 3b). Next, the stator and rotor blades were duplicated through a copy rotate operation so that they were equispaced along the circumference of their respective annular regions (Fig. 3c). The final fluid volume was created by subtracting the volume of the blades from the fluid volume (Fig. 3d).

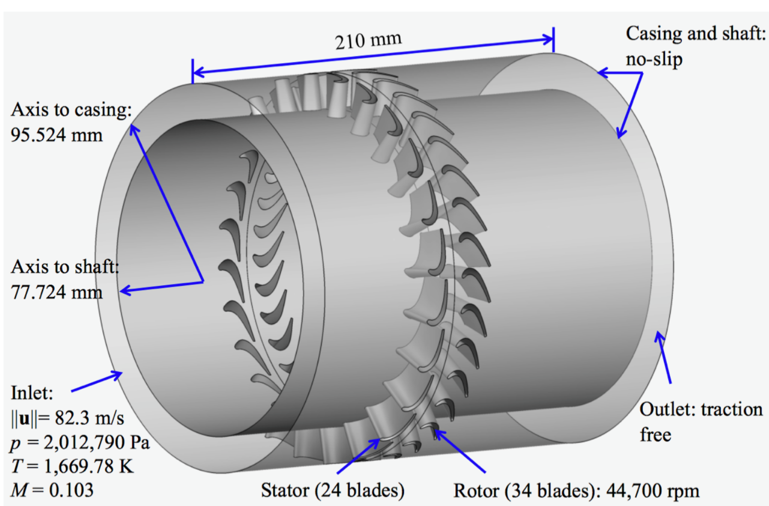
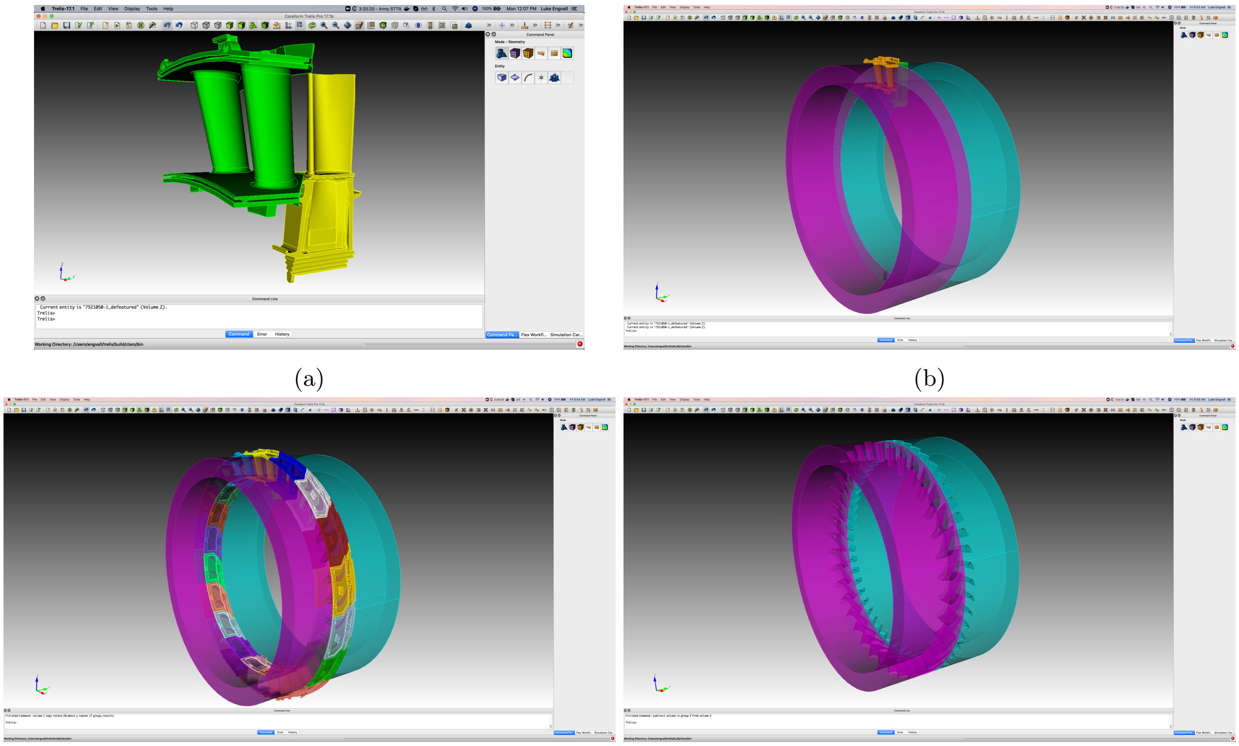


Figure 2: Schematic of a model single-stage axial turbine presented in the initial proposal.

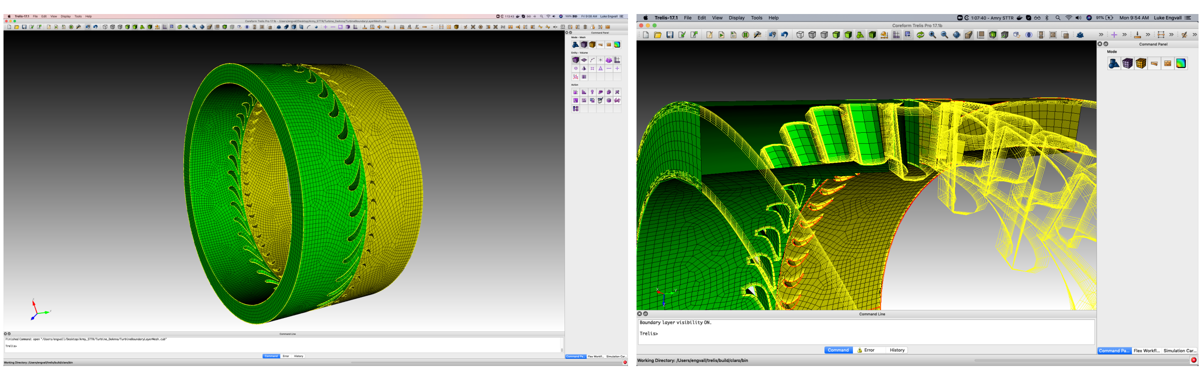
[1]Modeling the fluid domain as two separate volumes is critical for performing FSI simulations, as it allows for the rotor volume to rotate while the stator volume remains fixed. Dr. Evans details the efforts made to handle the sliding interface between the two volumes in Task 2.1.

Once the CAD model of the turbine was generated, Mr. Hortin then generated a quadrilateral mesh of the surface enclosing each of the two fluid volume (Fig. 4a). This surface mesh was then used to create a boundary layer mesh of hexahedral elements for each volume (Fig. 4b). During the next period of performance, we will complete Task 1.2 by converting these quadrilateral boundary layer meshes to U-spline models of the boundary layer.



(a) (b) (c) (d)

Figure 3: Coreform Trelis workflow used to build the CAD model of a simple single-stage axial turbine.(a) The stator blade (green) and rotor blade (yellow) components imported from a STEP file. (b) Fluid volumes for the rotor ring (purple) and stator ring (blue). (c) The blades duplicated around the circumference of the fluid volume. (d) The final CAD model of the fluid volumes.



(a) (b)

Figure 4: Meshes generated for the two fluid volumes. (a) The surface meshes for the stator ring (green) and rotor ring (yellow). (b) Cut view of the surface mesh, showing the boundary layer mesh in yellow wireframe. These meshes will be converted to U-splines in a future period of performance.

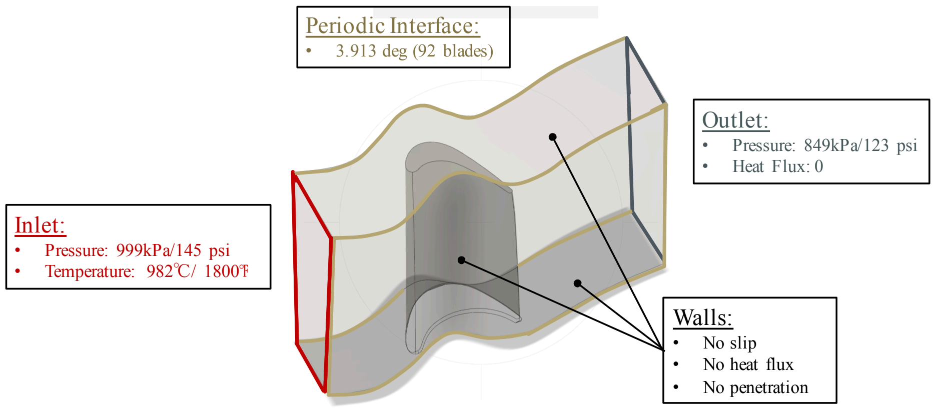
Task 2.1: Optimize CU Boulder code for U-spline CFD simulations

During the second period of performance, the CU Boulder team pursued several tasks in order to optimize the CU Boulder code PHASTA (Parallel Hierarchical Adaptive Stabilized Transient Analysis) for U-spline CFD simulations. First of all, PhD student Corey Wetterer-Nelson continued to lead work on writing a Coreform to PHASTA translator using the SCOREC APF (Attached Parallel Fields) library. Writing this translator requires expressing the U-spline basis over each element in the mesh in terms of a hierarchical finite element basis. Mr. Wetterer-Nelson previously developed such a translator for NURBS-based PHASTA CFD simulations, so he is well-equipped for this task. During this month, Mr. Wetterer-Nelson began outlining the required elements of the translator, and will be working closely with Coreform in Month 3 to implement the translator.

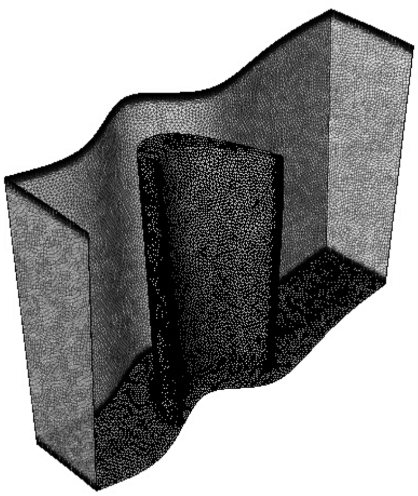
Second of all, Mr. Wetterer-Nelson also led the effort to optimize CU Boulder's mesh motion module. Of particular note was Mr. Wetterer-Nelson's work to generalize the mesh motion capabilities within PHASTA into a stand-alone module. Consequently, capabilities that were once purpose built for PHASTA can now be utilized with other third-party CFD simulation software. Moreover, Mr. Wetterer-Nelson made improvements to the mesh motion module to make it more robust to large deformation, and he further rewrote the module to utilize SCOREC's libraries so that it will be able to handle U-spline discretizations in the coming months.

Third of all, Dr. John Evans spearheaded the effort to optimize PHASTA's ability to handle sliding meshes, with a focus on the proposed challenge problem of a model single-stage axial turbine (see Fig. 2). In working on this task, Dr. Evans outlined a weak enforcement procedure based on Nitsche's method and upwinding as the best methodology to use. In addition, Dr. Evans identified several key barriers to ideal performance, including issues with numerical integration, change of connectivity, and load balancing. Fortunately, in previous months, Dr. Evans worked closely with PhD student David Gunderman (funded separately by a Lawrence Livermore National Laboratory fellowship) to develop an efficient way of exactly integrating moments over the sliding interface. Dr. Evans and Mr. Gunderman's approach is based on the application of Green's theorem to express integrals over surfaces/volumes as integrals over curves/surfaces. This yields significant performance gains over standard integration procedures. This approach has been submitted to the proceedings of SPM (Solid and Physical Modeling) 2020.

Last of all, PhD student DeAnna Gilchrist led an effort to develop benchmark tests that will later be used to verify the accuracy of U-spline CFD simulations. In particular, Ms. Gilchrist constructed a verification test problem inspired by the proposed challenge problem of a model single-stage axial turbine. The details of this verification test problem are displayed in Fig. 5. Ms. Gilchrist also created suitable finite element meshes for use with PHASTA to create verification data. CFD simulations with these meshes and the Spalart-Allmaras turbulence model are ongoing and are expected to complete early in Month 3. It is expected that a couple rounds of mesh refinement will need to be conducted to ensure the required wall mesh resolution is achieved.



(a)



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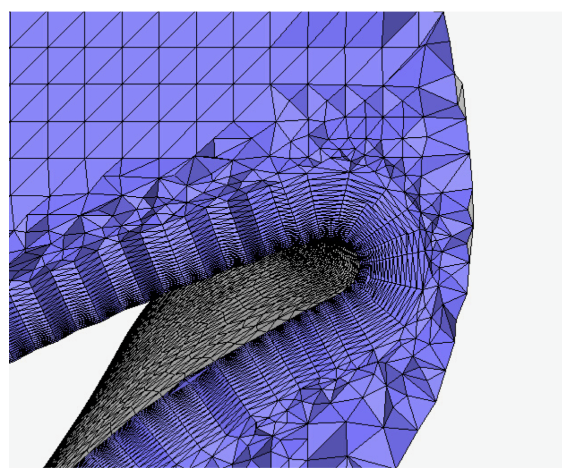

(c)

Figure 5: Setup for the simplified verification test. (a) Schematic showing boundary conditions for the CFD simulation. (b) A detailed view of the finite element mesh over all bounding surfaces. (c) A detailed view of the boundary layer mesh near the blade surface. In total, the mesh consists of 1.5 million tetrahedral elements. This mesh will be refined as we determine the actual friction velocity on the surface through iterative simulations so that the first mesh point off the wall corresponds to a small $y+$ value.