Statement of Work

Robot based Automated Fiber Placement System

1. Introduction

NASA Langley Research Center is interested in procuring a highly accurate, robot based, automated fiber placement system (AFPS) to support research on the design, analysis, manufacturing and evaluation of advanced composite materials and structures. The purpose of this document is to define the features, specifications, schedule, and funding requirements for a computer-numerical-control (CNC) robot based automated fiber placement system for thermoset composite materials. The complete system (i.e., base and exercised options) shall be fabricated, tested, and verified to be compliant with the SOW specifications at the vendor's facility prior to being shipped to, installed, and retested at the NASA Langley Research Center in Hampton, Virginia. Government acceptance will follow successful retesting of the complete system at NASA Langley.

2. System Hardware Specifications

The specified system shall be capable of fiber placement to establish processing parameters, evaluate the effects of processing variables, and perform advanced manufacturing research. As such accuracy, repeatability, and system flexibility are critical. NASA also plans to work with industry to extend this initial fiber placement capability beyond the current start of the art. It is therefore critical that the system incorporate a quick-change mechanism, and also be capable of accommodating additional electrical and pneumatic lines required by future end effectors (e.g., stitching, thermoplastic fiber placement, non-destructive inspection). The programming, simulation, and control software packages shall incorporate the flexibility to be modified for multiple system configurations. The system shall comprise an integrated multi-degree-of-freedom (DOF) robot-based automated fiber placement system (AFPS) that meets the specifications listed in section 2. The specification has been separated into system level requirements, a base commercial 6-axis robot with quick-change mechanism and controls, an optional linear track with integrated carriage, an optional fiber placement head, and an optional rotary table.

2.1. System Level Requirements

The base AFPS shall be capable of meeting the following system level requirements:

2.1.1. Shall be designed to incorporate up to 8 degrees of freedom (DOFs). Of the 8 DOFs, 6 DOFs shall come from the commercially available robot, one DOF shall come from a linear track with carriage, and the one remaining DOF shall come from a rotary table.

2.1.2. Shall have demonstrated ±3-sigma spatial positioning accuracy (bias errors) of ≤ ± 0.020 inches, and demonstrated ±3-sigma spatial positioning precision (random errors) of ≤ ± 0.005 inches measured at the center point of the quick-change mechanism within the system work envelope.

2.1.3. Shall have demonstrated ±3-sigma spatial orientation accuracy (bias errors) of ≤ ± 0.10 degrees, and demonstrated ±3-sigma spatial orientation precision (random errors) of ≤ ± 0.025 degrees measured at the face of the quick-change mechanism within the system work envelope.

2.1.4. Shall have the capability to incorporate a computer controlled linear track and carriage that is a between 25 and 35 feet long to provide linear motion to the robot.

2.1.5. Shall have the capability to incorporate a computer controlled rotary table with mounting holes and positive indexing features to accurately hold parts and/or tooling during the layup process.
2.1.6. The AFPS fiber placement head shall be a self-contained unit with all of the components necessary to simultaneously fiber place a minimum of 12 pieces of ¼" wide thermoset composite prepreg slit tape material. In order to be considered self-contained, the single unit shall incorporate all of the prepreg fiber spools, redirects, heater(s), compaction head(s), and other hardware necessary to fiber-place the composite material. This fiber placement head shall interface with the specified quick change mechanism.
2.1.7. Shall incorporate a quick change mechanism capable of automatically (i.e., without human intervention) placing the proposed fiber placement head into a work stand and then picking up another end effector (future purchase) with an identical interface. In addition to the automatic mechanical connection, the system must also automatically disconnect and reconnect all power, data, and pneumatic lines required to operate the proposed end effector.
2.1.8. Shall include all control cabinets and controllers necessary for performing automated fiber placement with the proposed fiber placement head, one 6-DOF robot, one linear track, and one rotary table.
2.1.9. Shall include all air, hydraulic, power, data lines, and cable trays required internally and between AFPS components necessary to operate the AFPS in a manner that meets all requirements. The system shall be capable of operating off of, and be compatible with, a NASA-provided 480V/3phase, 150A max power disconnect and standard shop air supply.
2.1.10. Shall include an operator station with all of the necessary hardware to interface with and control the proposed AFPS. This shall at a minimum include a computer that is capable of running all necessary control and simulation software and connections to the AFPS controllers.
2.1.11. The complete system (Base + all exercised options) shall contain all deliverable items specified in Section 9.

2.2. Base System: 6-Axis Robot with Quick Change Mechanism, and AFPS Controls

<u>6-Axis Robot with Quick Change Mechanism</u>:

The proposed 6-axis robot shall at a minimum meet the following requirements.

2.2.1. Commercially available industrial robot
2.2.2. Six kinematic degrees-of-freedom (DOF) to provide full control of position and orientation of the quick-change mechanism within the work envelope
2.2.3. Payload Capacity shall be a minimum of 1,625 lbs. (750 kg)
2.2.4. Work Envelope:
  2.2.4.1. Vertical: ≥ 14.5 feet relative to robot base to center of quick-change mechanism
  2.2.4.2. Radial: ≥ 13 feet relative to the center of robot base to center of quick-change mechanism
  2.2.4.3. Rotational: ≥ ±150˚ relative to the vertical axis through the center of the robot base, normal to the floor.

2.2.5. Shall provide closed-loop position feedback at all joints (i.e., degrees-of-freedom). This feedback information shall be provided in an ASCII format to document that the actual fiber placement is consistent with the "as-programmed" position within the system accuracy and precision requirements specified in Sections 2.1.2 and 2.1.3.
2.2.6. Shall be capable of meeting the system accuracy and precision requirements specified in Sections 2.1.2 and 2.1.3.
2.2.7. Shall incorporate a demonstrated quick change mechanism that is capable of automatically (i.e., without human intervention) placing the fiber placement head (Ref. Option 2) into a work stand, and then picking up another end effector (not part of this procurement) with an identical interface. In addition to an automatic mechanical connection, the system shall automatically disconnect and reconnect all power, data, and pneumatic lines required to operate the proposed fiber placement head.

AFPS Controls:

The AFPS controllers shall meet the following minimum requirements.

2.2.8. Shall include control cabinets with all CNC controllers necessary to perform automated fiber placement with the proposed fiber placement head, one 6-DOF robot, one linear track, and one rotary table. Cabinets shall be sized to accommodate 8 degrees of freedom as part of the base system.
2.2.9. One operator station with all of the hardware necessary to interface with and control the proposed AFPS. This shall at a minimum include a computer capable of running all necessary control and simulation software and connections to the AFPS controllers.
2.2.10. The control system shall accept or incorporate real-time position compensation based on robot orientation, location, loading, mounting (e.g., floor or carriage on linear track).
2.2.11. Be capable of interfacing with alternate end effectors such as drilling / trimming, thermoplastic fiber placement, or stitching heads.

8' x 12' layup table:

The proposed fiber placement system shall come with one (1) flat layup table that at a minimum meets the following requirements.

2.2.12. Metallic based table with a replaceable top surface appropriate for composite layups
2.2.13. Minimum work surface size: 8' x 12' (Nominal)

2.3. Option 1: Linear Track with Integrated Carriage

If Option 1 is exercised by the Government, the Contractor shall deliver a linear track with integrated carriage for robot-to-track interface that enables translational travel for the robot and fiber placement head. Option 1 shall meet the following minimum requirements:

2.3.1. The linear track and integrated carriage assembly shall interface with the robot base and provide minimum of 25 feet, and a maximum of 35 feet, of linear travel. Exercising

of Option 1 extends the system work envelope defined in Section 2.2.4 to include the length of the linear track.

2.3.2. The system with exercised Option 1 shall meet the accuracy and precision requirements identified in Sections 2.1.2 and 2.1.3 along the entire track length.

2.3.3. Shall include all air, hydraulic, power, and data lines. All lines shall be of sufficient length to accommodate the full range of robot motion along the linear track.

2.3.4. Shall include a flexible cable tray sized to accept a minimum of 2 times the baseline capacity of air, hydraulic, power, and data lines required by the AFPS components. This is to ensure that additional capabilities can be added to the cable tray as the system evolves.

2.3.5. The carriage shall integrate seamlessly and simultaneously with the other 7 system degrees of freedom to permit the placement of composite material at a minimum laydown rate of ≥ 1000 inches/minute along the linear track direction.

2.4. Option 2: Fiber Placement End Effector, Self-Contained, Modular, Minimum 12-Tow

If Option 2 is exercised by the Government, the Contractor shall deliver a self-contained, fiber placement end effector that is fully compatible and integrated with the AFPS. Option 2 shall meet the following minimum requirements:

2.4.1. Shall be a self-contained, modular unit containing a minimum of 12 tows or slit tape and all of the components necessary to fiber-place unidirectional thermoset composite prepreg tow or slit tape materials. In order to be self-contained, the single unit must incorporate all of the composite prepreg spools, redirects, heater(s), compaction head(s), and all other hardware necessary to fiber-place composite materials.

2.4.2. Shall have a demonstrated capability to place 1/4-inch wide slit tape with any thickness between 0.0025 and 0.010 inches.

2.4.3. Shall be capable of a minimum laydown rate of ≥ 1000 inches/minute.

2.4.4. Shall have the capability to be automatically dropped off and picked up by the AFPS's automatic quick change mechanism (Ref. Section 2.2.7).

2.4.5. Shall be capable of conversion to placement of 1/8-inch wide, or 1/2-inch wide, slit tape material with minimal additional hardware required.

2.5. Option 3: Rotary Table

If Option 3 is exercised by the Government, the Contractor shall deliver a rotary table that enables rotary motion of tooling for presentation to the robot and fiber placement head. Option 3 shall meet the following minimum requirements:

2.5.1. Shall consist of a flat rotating table with mounting holes and positive indexing features to attach parts and/or tooling and a numerically controlled drive motor that interfaces with the proposed system controller. The programmable rotary table shall work seamlessly and simultaneously with the other system degrees of freedom to support the accurate placement of composite material.

2.5.2. Shall include all required air, hydraulic, power, and/or data lines.

2.5.3. Size: ≥ 6' diameter

2.5.4. Capacity: ≥ 20,000 lbs.

2.5.5. Speed: ≥ 5 rpm

2.5.6. Acceleration time, 0-180 deg.: ≤ 6 seconds
2.5.7. Indexing Precision: ± 5 Arc-Seconds
2.5.8. Repeatability Accuracy: ± 5 Arc-Seconds
2.5.9. Max Table Run-out: 0.0015”
2.5.10. Attachment Bolt Holes / Features for attaching parts and/or tooling

3. Training

The contractor shall provide a minimum of 1-week training to up to 10 trainees at the NASA Langley Research Center, Hampton, Virginia.

4. Safety

The Contractor shall incorporate safeguards consistent with OSHA electrical, and lockout/tagout regulations and a risk assessment. The Contractor shall as a minimum design and build the Robot based AFPS to meet the electrical safety regulations of OSHA 1910 Subpart S , NFPA 70 (National Electric Code), NFPA 70E and meet the lockout/tagout regulations of OSHA 1910.147, sections (a)(2)(ii) and (c)(2)(iii). The Robot based AFPS shall incorporate personnel safety features based on a risk assessment that meets ANSI/RIA R15.06-2012 “American National Standard for Industrial Robots and Robot Systems-Safety Requirements”. The minimum safety features shall include a light curtain or similar safety system to ensure that personnel or physical obstructions are not present on the linear track during operations; a controller able to recognize a signal from a sensor on a “safety gate/door” that is part of an access safety perimeter around the equipment and command the equipment to a safe operational state; and emergency stop buttons accessible to operator personnel both at the control console and on any remote control devices used to operate the system.

During the installation of the Robot Base AFPS the operational practices of the Contractor shall conform to OSHA and LaRC lifting requirements. Installation of the Robot based AFPS at LaRC the operators of powered industrial trucks (forklifts, pallet jacks, and other motorized material handling equipment) shall meet the regulations in OSHA 29 CFR 1910.178. If the facilities equipment is to be used for this operation the Contractor shall provide verification of their operator’s certification. Operators of cranes (mobile cranes, bridge cranes, gantry cranes, truck-mounted booms, and swing-arm shop cranes) shall meet the regulations in OSHA 29 CFR 1910.179. If the government overhead crane is to be used for this operation the Contractor shall provide verification of the operator’s certification and shall be required to demonstrate proficiency on the government equipment. Should a mobile crane or truck-mounted boom style crane be brought onto the center for use, a visual inspection will be required by the government. Prior to use of all the rigging equipment and crane certification, and personnel certifications/licenses must be verified by the government.

The Contractor shall provide written safety instructions identifying the hazards identified and the method of mitigating the hazard. The instructions shall be included as part of the user’s manuals listed in the deliverable items section. The Contractor shall present all safety information as part of the 1-week training described in section 3.

5. Initial System Checkout at Contractor's Facility

The Contractor shall perform an end-to-end checkout of the base system plus all exercised options at their facility prior to shipping the hardware to NASA. The purpose of this test is to ensure that the system meets the functional, accuracy, and precision requirements provided in this document. The functional checkout shall at a minimum include fiber placing NASA provided slit tape pre-preg material onto the flat table provided as part of the base system or other mutually agreed upon surface. If option 3 is exercised, the Contractor shall also fiber place the provided slit tape material onto a mutually agreed-upon mandrel mounted to the rotary table. The checkout shall include verification and documentation of the system's precision and accuracy using an external measurement system such as a laser tracker and targets. NASA personal shall be given full access to and be present for the system checkout activities and all collected data. The contractor shall generate and deliver an initial calibration report to NASA that documents the accuracy and precision of the base system plus all exercised options prior to shipping the hardware. The Contractor shall use their company owned software to perform the programming and operations associated with this system level checkout. Note that this software is not a deliverable under this contract.

6. Shipping & Installation at LaRC

The contractor shall deliver the system to NASA Langley within 12 months after award. If any option is exercised after 6 months following award, the contractor shall deliver the system to NASA Langley within 15 months after award. The contractor shall install a fully integrated system inclusive of all options that are exercised. The contractor shall install the system within 1 month after delivery to NASA Langley.

7. Final Acceptance Testing

The Contractor shall perform an end-to-end checkout of the base system plus all exercised options once it is installed at the NASA LaRC facility. The purpose of this test is to ensure that the installed system still meets the functional, accuracy, and precision requirements provided in this document. The functional checkout shall at a minimum include fiber placing NASA provided slit tape pre-preg material onto the flat table provided as part of the base system or other mutually agreed upon surface. If option 3 is exercised, the Contractor shall also fiber place the provided slit tape material onto a mutually agreed-upon mandrel mounted to the rotary table. The checkout shall include a demonstration and documentation of the system's precision and accuracy. NASA personal shall be given full access to and be present for the system checkout activities and all collected data. The contractor shall generate and deliver a final calibration report to NASA that documents the accuracy and precision of the base system plus all exercised options installed at the NASA facility. The Contractor shall use their company owned software to perform the programming and operations associated with this system level checkout. Note that although the software is not a deliverable under this contract, NASA shall as part of the final calibration report receive any and all correction factors required to achieve the required system accuracy.

8. Warranty

The Contractor shall provide a minimum 1-year warranty for the AFPS commencing upon acceptance in accordance with Section 7.

9. Deliverables

Base Robot (BR) Deliverables:

- BR-1 An enhanced accuracy, calibrated, 6-axis commercial robot that meets the specifications in Sections 2.1 and 2.2.
- BR-2 An integrated quick change mechanism for the automated pickup and drop-off of fiber placement end effectors
- BR-3 Control Cabinets with all controllers necessary to perform fiber placement
- BR-4 Operator station with PC
- BR-5 All specialized tools for cleaning and maintenance.
- BR-6 Initial calibration report that documents the robot spatial positioning and orientation accuracy and precision with a representative end effector mass at the Contractor's facility.
- BR-7 Final calibration report that documents the robot spatial positioning and orientation accuracy and precision with a representative end effector mass after it is delivered and installed at NASA LaRC.
- BR-8 All required user's manuals in both electronic and written formats.
- BR-9 An 8' x 12' layup table.

Option-1, Linear Track (LT) Deliverables:

- LT-1 Linear track & carriage system, between 25 and 35 feet in length, as described in Section 2.3.
- LT-2 Specialized tools for cleaning and maintenance.
- LT-3 All necessary air, hydraulic, power, data lines, and flex track required for operation of the proposed fiber placement system along the linear track.
- LT-4 User's manuals in both electronic and written formats.

Option-2, Fiber Placement End Effector, Self-Contained, Modular, Minimum 12-Tow (FP) Deliverables:

- FP-1 Fiber placement end effector, as described in Section 2.4.
- FP-2 Specialized tools for cleaning and maintenance.
- FP-3 Fixed stand for storing and maintaining fiber placement end effector.
- FP-4 User's manuals in both electronic and written formats.

Option-3, Rotary Table (RT) Deliverables:

- RT-1 Rotary table, as described in Section 2.5.
- RT-2 All lines and connections (i.e., power, data) required to operate the rotary table and interface with the proposed fiber placement system.
- RT-3 Specialized tools for cleaning and maintenance.
- RT-4 User's manuals in both electronic and written formats.