Progress on the Development of a Step Height Sensor for the BOLT Flight Vehicle

Brett Bathel, Joshua Weisberger, Stephen Jones, Scott Berry

NASA Langley Research Center, Hampton, VA

Copyright 2021 United States Government as represented by the Administrator of the National Aeronautics and Space Administration.
No copyright is claimed in the United States under Title 17, U.S. Code. All Other Rights Reserved.
Published by the American Institute of Aeronautics and Astronautics, Inc. with permission.

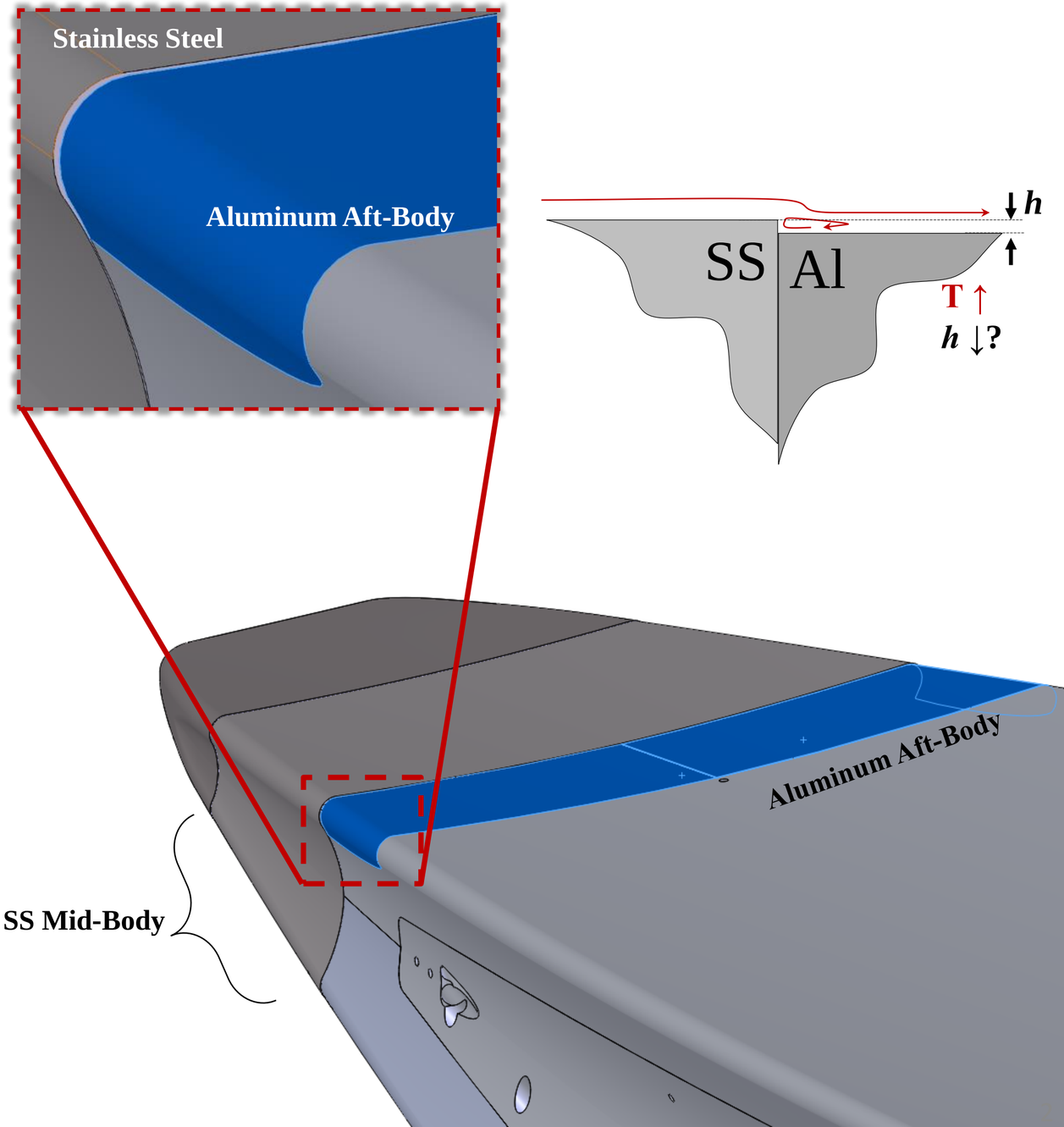
Inspiration for New Instrumentation

- BOLT flights are intended to provide better understanding of hypersonic boundary layer flow at flight conditions
  - Influence of rearward-facing step on boundary layer on BOLT1
    - Berry, S.A., Wheaton, B.M., and Chynoweth, B.C., "*Secondary Side Considerations for Boundary Layer Transition Flight Experiment*," to appear in Journal of Spacecraft and Rockets
  - BOLT2 examining different materials and joints

- Material from BOLT1 purposely removed along a portion of the upstream portion of the aluminum aft-body
  - Thermal/mechanical loading will change step height over the course of the flight
  - Worst case step height of +102 µm

- No instrumentation available for step height measurement on BOLT 1 flight vehicle
  - Work aimed at future flight projects – intended to fly sensor as proof-of-concept on BOLT2, but COVID resulted in significant delays
  - Step heights have been predicted using computational thermal/structural analysis methods

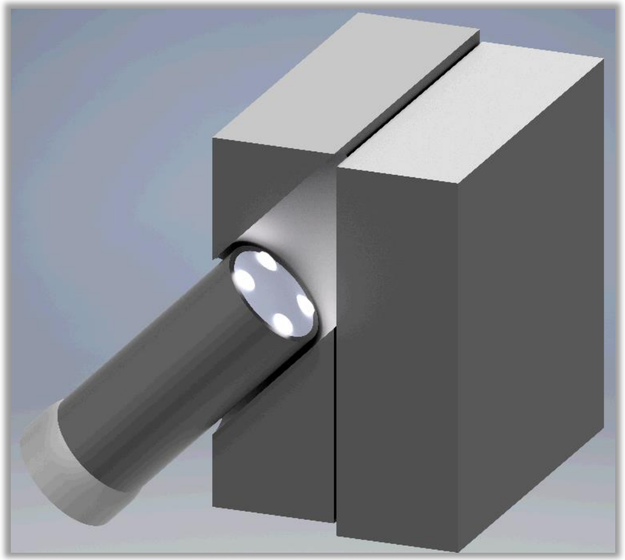
- Lack of step sensor on BOLT1 flight resulted in large uncertainty in step heights
  - Limits our understanding of the boundary conditions in flight



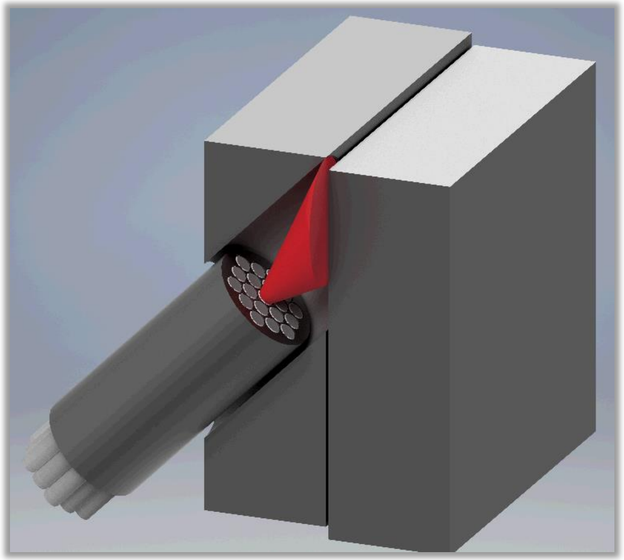
Objective of the Work

- Develop compact optical step height measurement capability in the laboratory
  - Needs:
    - Resolution of at least 10 µm with relatively high precision/accuracy
    - Can be transitioned to flight instrument relatively easily
    - Compact design that can be easily embedded into vehicle surfaces
    - Simple calibration procedure
- Approaches
  - **<u>Miniaturized camera</u>**
  - Fiber bundle array

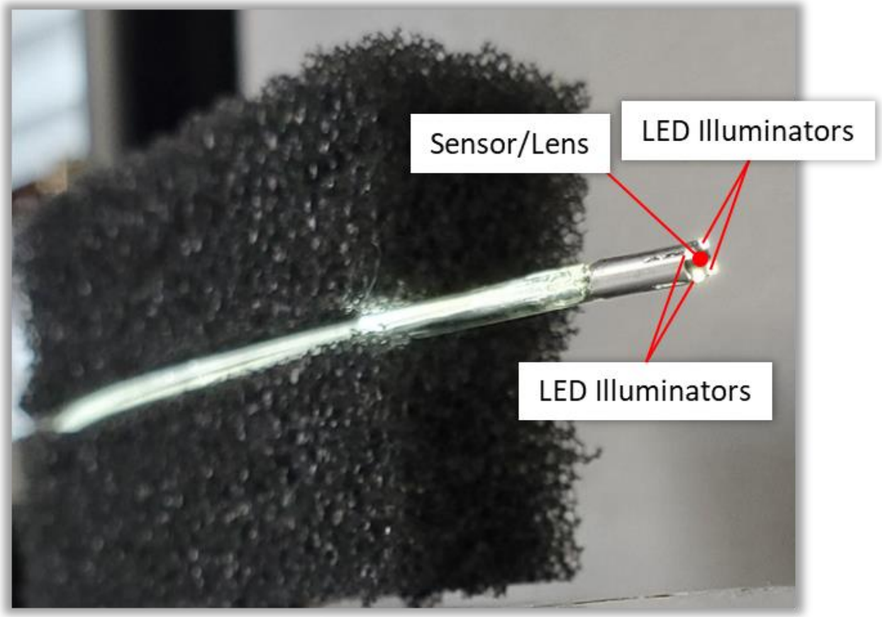
Miniature Camera



Fiber Bundle

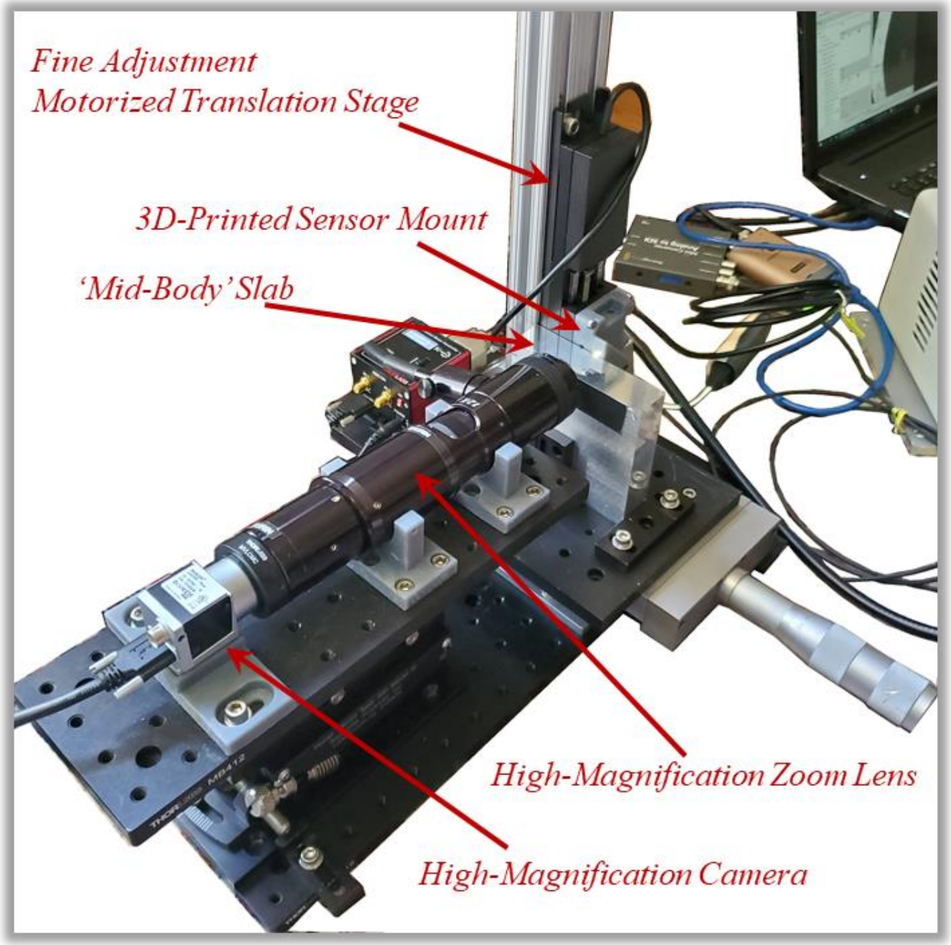


Micro ScoutCam FLEX LED Camera (1.6 mm diameter)



Experimental Setup and Data Acquisition: Miniaturized Camera Method

- Step height sensor test kit
  - Key components
    - Sensor: ScoutCam Flex LED camera, 1.6 mm diameter
      - Modified to allow for LED power control
    - Mount: Stainless steel tube embedded within 3D-printed camera mount for 0 and 45° camera views
      - Only considered 45° mounting configuration in this work
    - Position: 50-mm travel motorized translation stage with fine adjustment capability (0.05 µm step size)
    - Nose slab: Tight tolerance aluminum block
    - Position measurement: USB camera with high magnification lens
  - Data acquisition
    - Automated data collection in Matlab
    - 25-image-average collected from each camera at each step height

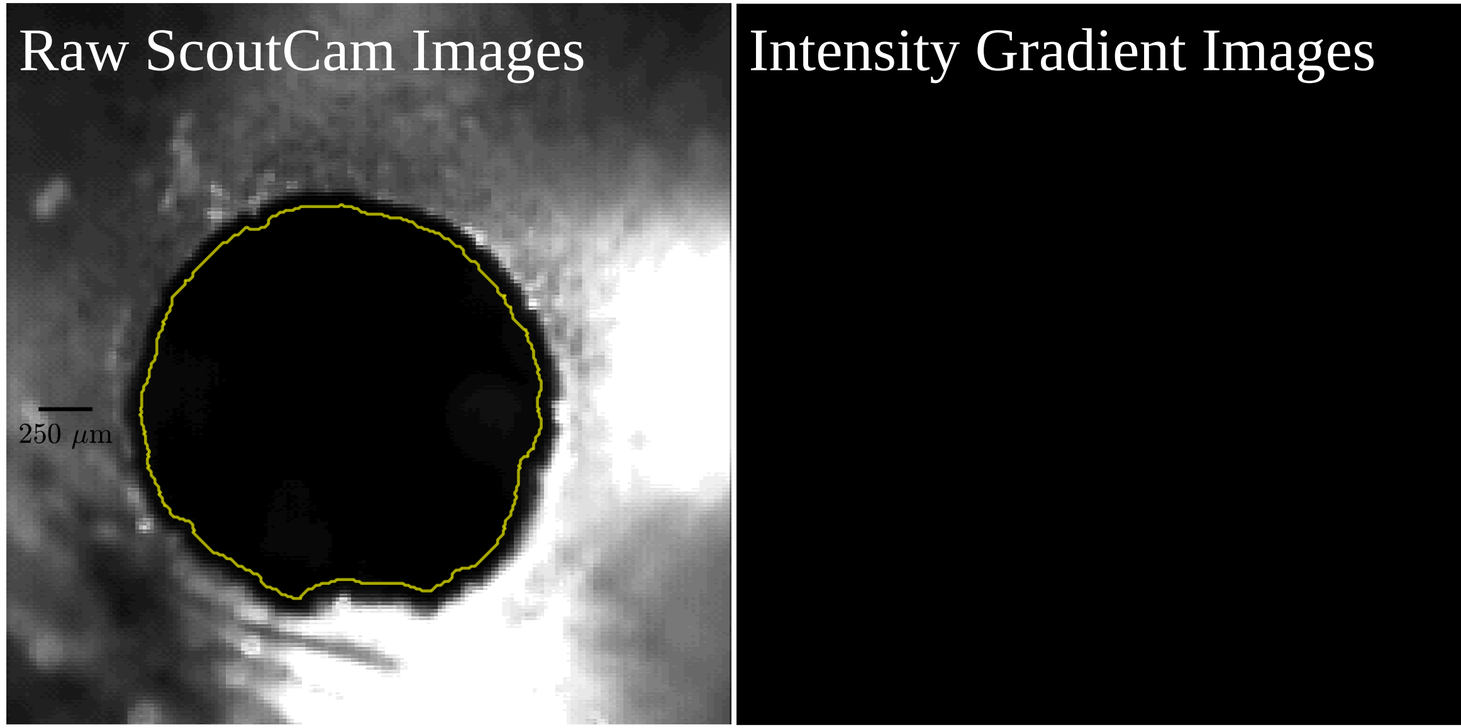


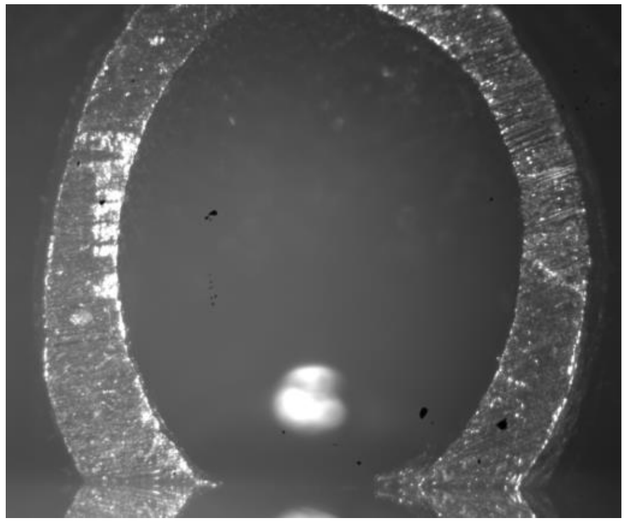




Preliminary Results: Miniaturized Camera Method

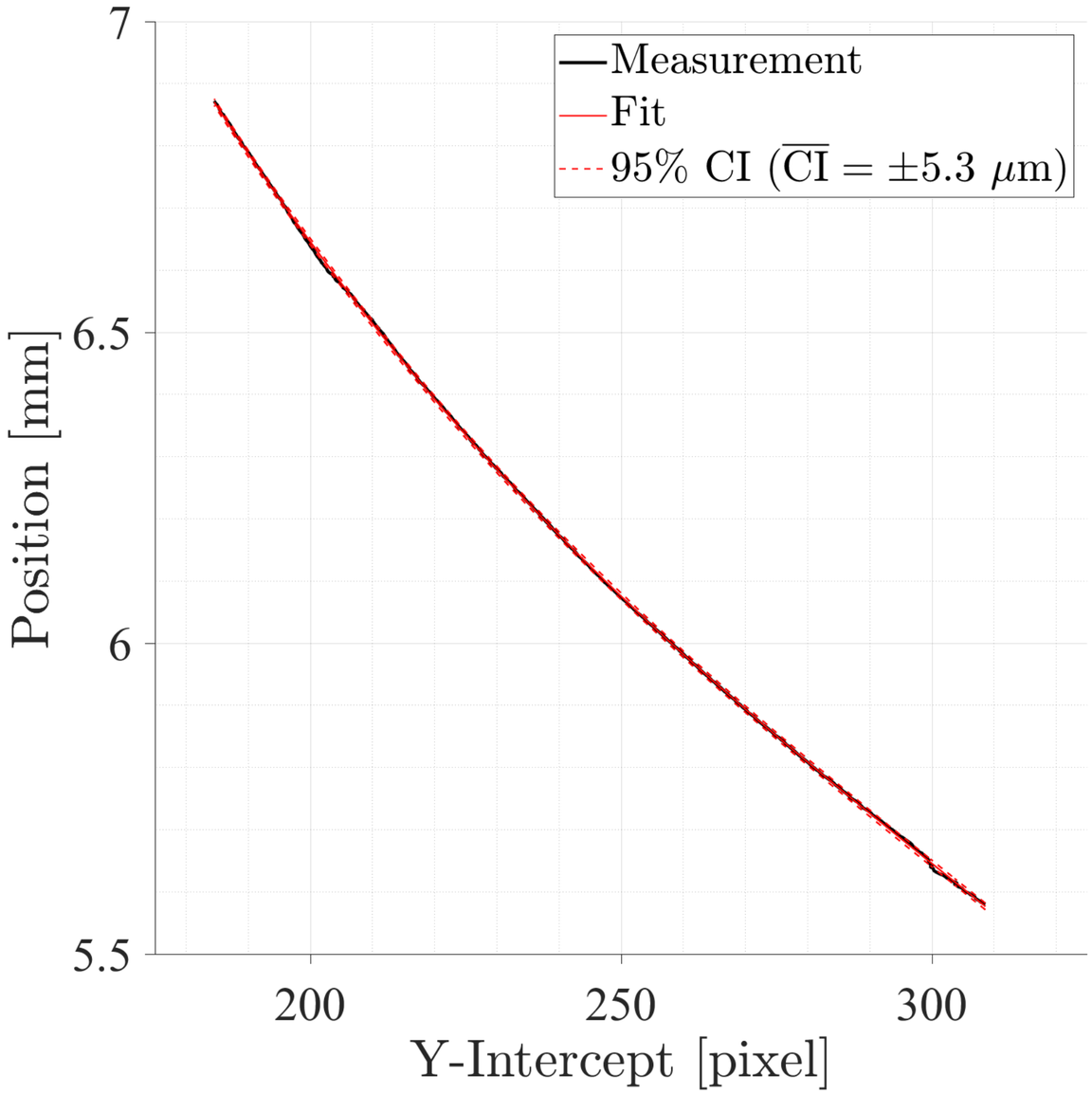
- Image data
  - Showing data from ScoutCam, data from high-magnification camera not used in this work
  - Using two methods to estimate step height
    - Compute intensity gradient in vertical direction and fit line to edge points
      - Top-right image shows these images
      - Red data corresponds to edge points
      - Green line represents edge position
    - Compute spatially-averaged intensity signal
      - Region in within yellow boundary in top-left image used to compute mean intensity





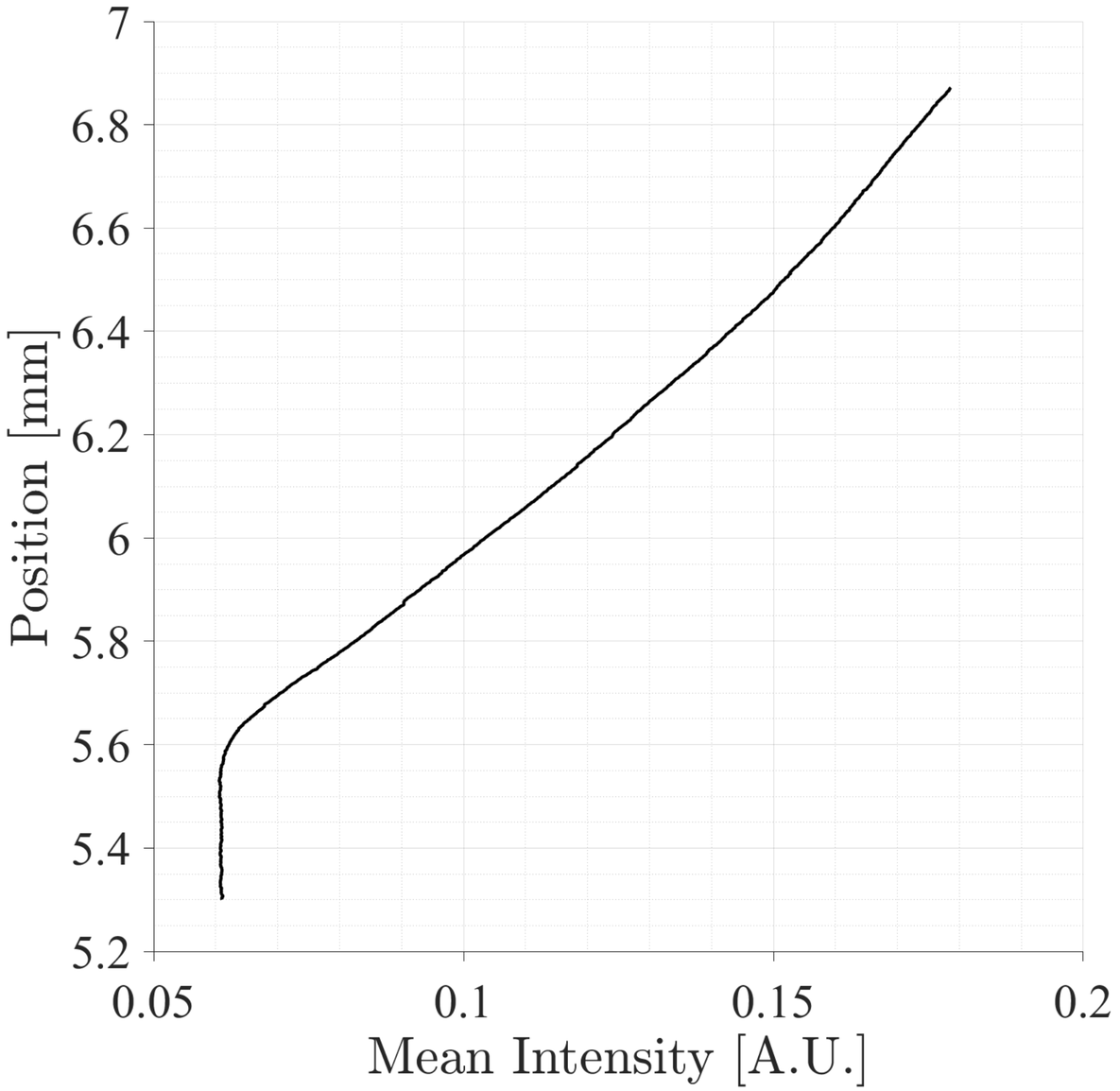
Preliminary Results: Miniaturized Camera Method

- Image data
  - Showing data from ScoutCam, data from high-magnification camera not used in this work
  - Using two methods to estimate step height
    - Compute intensity gradient in vertical direction and fit line to edge points
      - Top-right image shows these images
      - Red data corresponds to edge points
      - Green line represents edge position
    - Compute spatially-averaged intensity signal
      - Region in within yellow boundary in top-left image used to compute mean intensity



Preliminary Results: Miniaturized Camera Method

- Image data
  - Showing data from ScoutCam, data from high-magnification camera not used in this work
  - Using two methods to estimate step height
    - Compute intensity gradient in vertical direction and fit line to edge points
      - Top-right image shows these images
      - Red data corresponds to edge points
      - Green line represents edge position
    - Compute spatially-averaged intensity signal
      - Region in within yellow boundary in top-left image used to compute mean intensity



Summary

- Discussed need to characterize step heights on future flight vehicles and proposed optical sensor methods that can be used for step height measurements

- Designed and constructed small test stand to evaluate optical sensors

- Performed preliminary measurements with miniature camera sensor and showed ability to measure step height with resolution approaching 10 µm