Investigation into the use of the Concept Laser QM system as an in-situ research and evaluation tool

Stacey Bagg NASA MSFC EM32
Zachary Jones NASA MSFC EM42
Justin Rowe NASA MSFC 2014 Summer Intern (EM42)

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Relevance

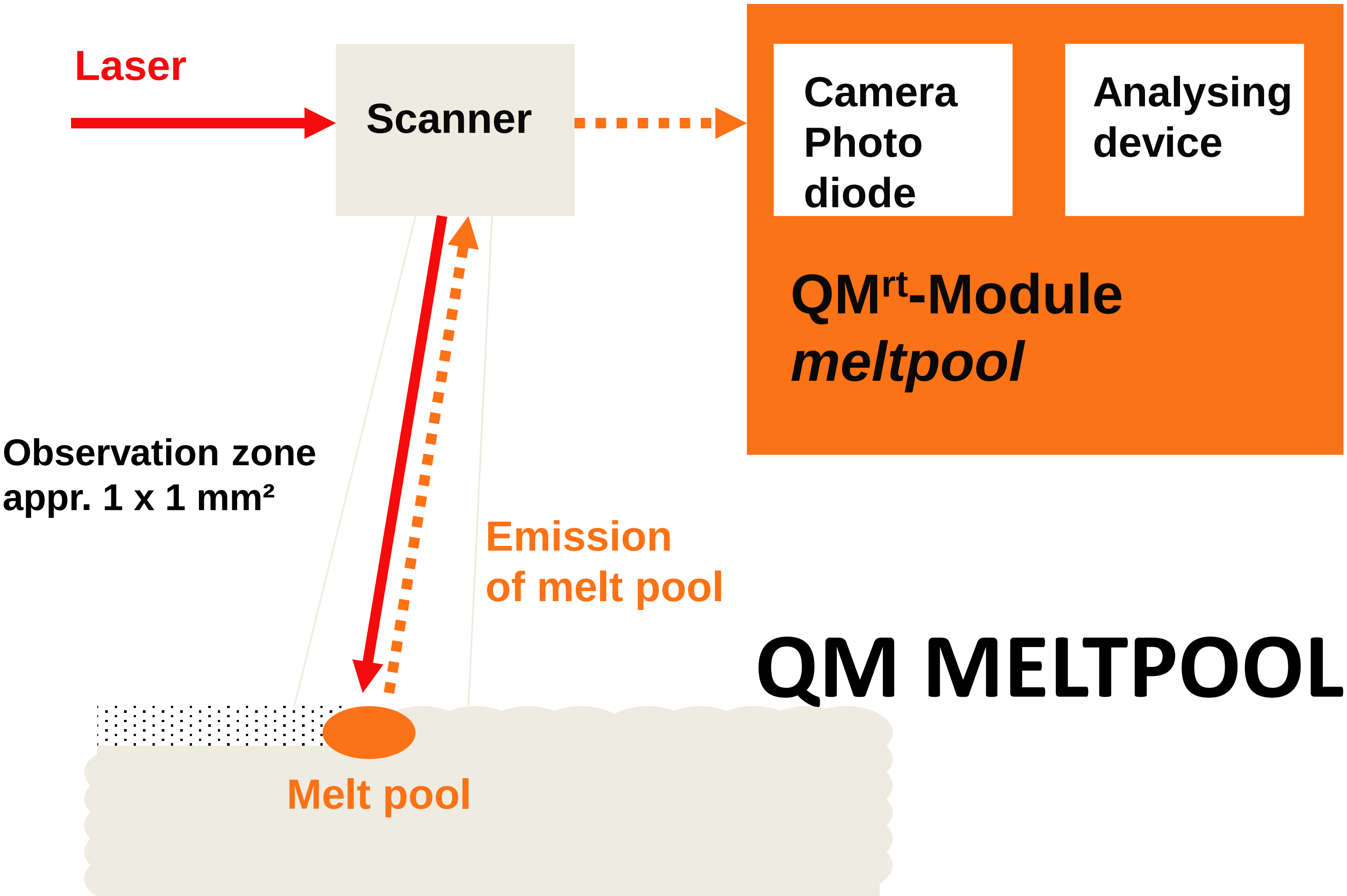
- ➢ NASA Marshall Space Flight Center (MSFC) is investigating “printing” complex, expensive, and/or schedule intensive rocket engine components, using Direct Metal Laser Sintering (DMLS) which has shown clear advantages to other manufacturing methods
- As part of this effort, MSFC invested in Concept Laser technologies in order to refine our understanding of the printing process, and research the process sensitivities and resulting material properties
- Additionally, MSFC must develop a method to qualify printed components for space flight use, which indicates process control and inspection
- ➢ Both of these goals require in-situ process observation

CL QM System

- MSFC invested in Concept Laser GmbH Quality Management (QM) modules on the M2 Cusing machine, which are marketed to provide process monitoring for a "quality-controlled fabrication process"
  - *"Quality management (QM) modules make it possible to ensure and document optimum component quality"* – concept-laser.de
- Two in-situ modules are currently available and in-use: QM Meltpool and QM Coating
  - QM Meltpool monitors the molten area during a scan, using a near-infrared camera and photodiode. Data from this module is intended for post-process inspection to ensure conformance to a reference build
  - QM Coating monitors the powder layer surface and feedback control allows automatic adjustment of powder dose rates to minimize short feeds, while maximizing powder use

➢ So, can NASA use these to meet our process observation needs?

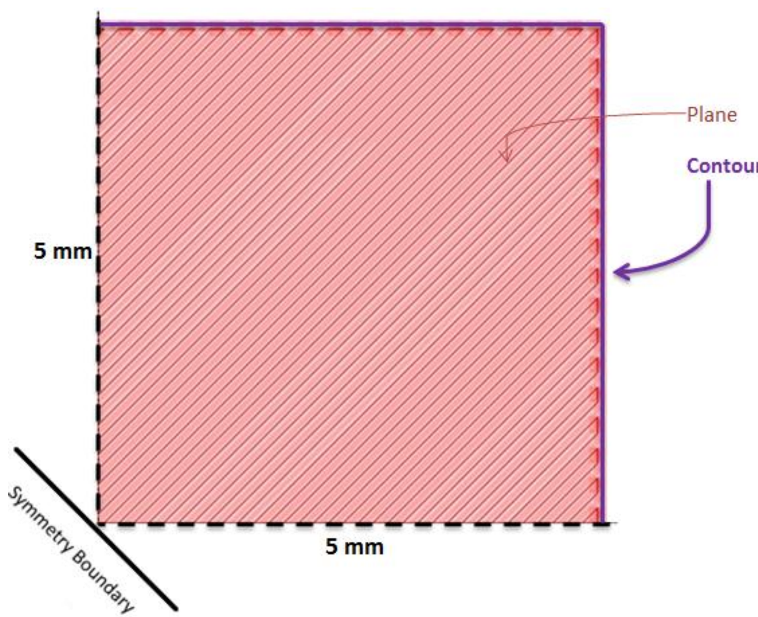
QM MELTPOOL


Laser
Scanner
Camera
Photo
diode
Analysing
device
QMrt-Module
meltpool
Observation zone
appr. 1 x 1 mm²
Emission
of melt pool
Melt pool

System Description

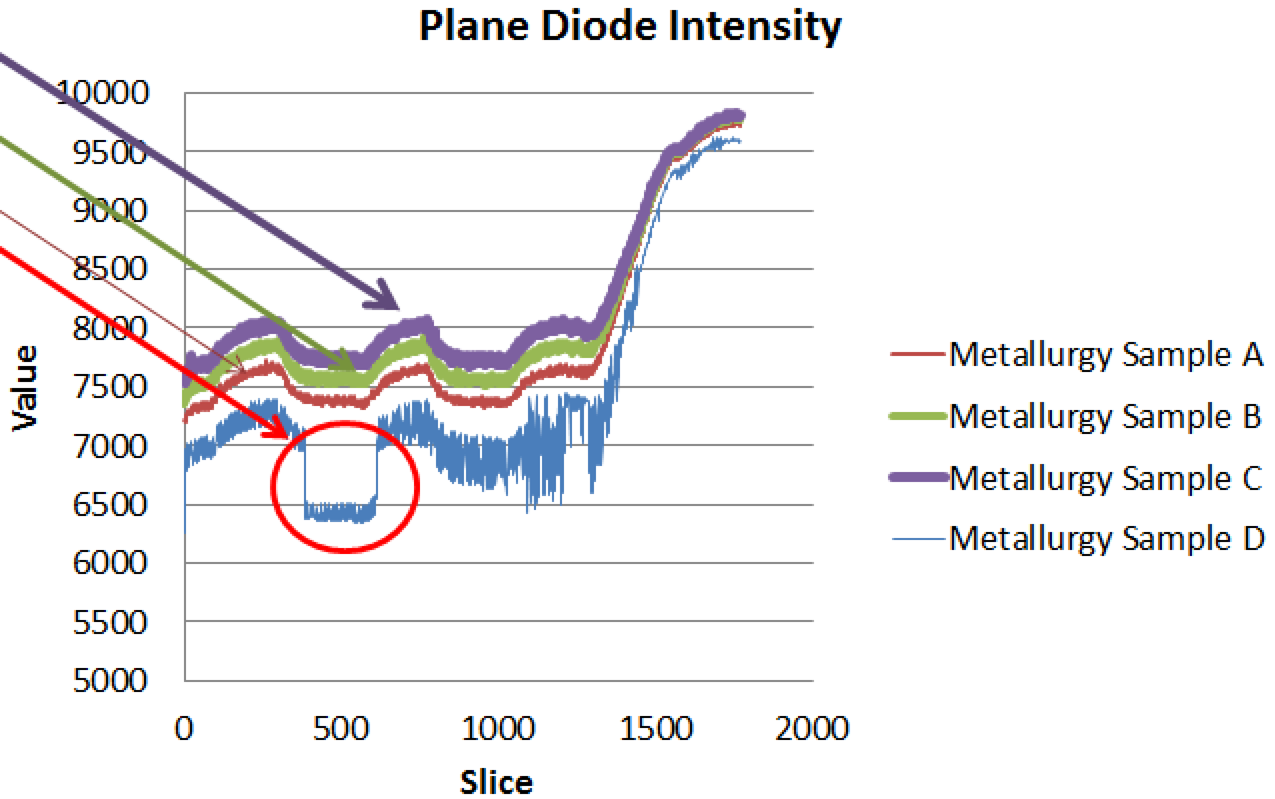
- A high-speed IR Camera measures the integrated intensity of the radiation and captures images. Software determines from camera images how many pixels are within a threshold color level corresponding to molten material
- A Photodiode measures the brightness intensity of the melt pool

<table>
<tr><td rowspan="6">Part</td><td rowspan="6">Layer</td><td rowspan="3">Contour</td><td>Diode Intensity</td><td>From Photodiode, average intensity value of contour trace</td></tr>
<tr><td>Meltpool Intensity</td><td>From Camera, average integrated IR intensity of contour trace</td></tr>
<tr><td>Meltpool Area</td><td>From Camera, average number of pixels above threshold color level during contour trace</td></tr>
<tr><td rowspan="3">Plane</td><td>Diode Intensity</td><td>From Photodiode, average intensity value of bulk material / hatch scan</td></tr>
<tr><td>Meltpool Intensity</td><td>From Camera, average integrated IR intensity of bulk material / hatch scan</td></tr>
<tr><td>Meltpool Area</td><td>From Camera, average number of pixels above threshold color level during hatch scan</td></tr>
</table>



Marketed Use

- Compare geometrically identical builds qualitatively to identify anomalies:
  - Good
  - Good
  - Good
  - Anomaly



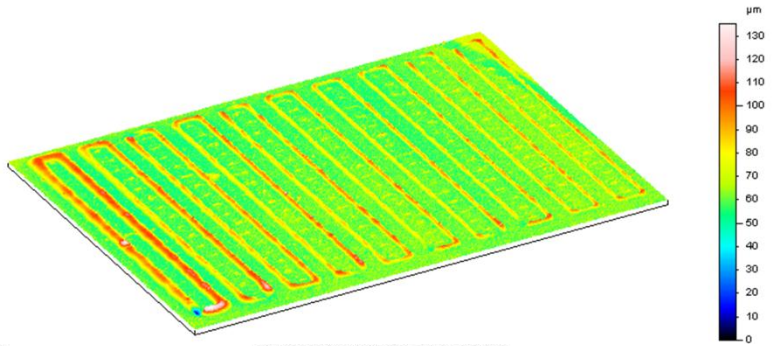
Potential NASA Use

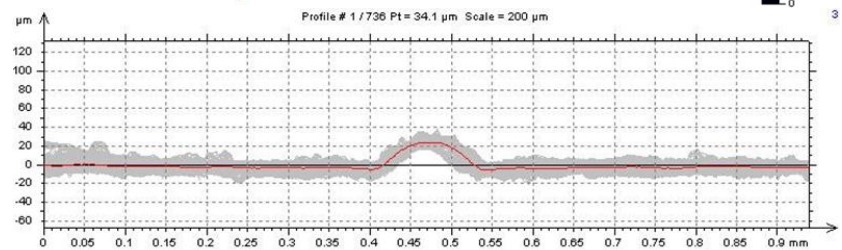
- Research:
  - Identify how changing parameters change the size, shape, and temperature of the melt pool
    - Weld thermal gradients and melt pool / solidification path shape can strongly affect properties
  - Provide in-situ data to calibrate, and ultimately validate, computational process models (e.g. thermal history prediction)
- Process improvement:
  - Can identify areas of heat buildup, and adjust parameters to reduce heat input to a goal value
- Qualification:
  - Set quantitative boundaries on melt pool characteristics that are known to produce good material

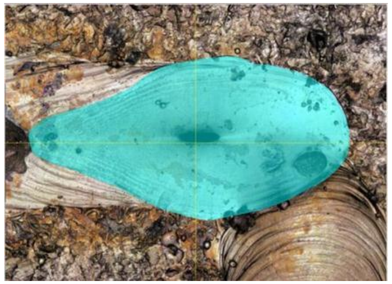
➢ So, can we extract quantitative measurements from this qualitative system?

Quantification of Melt Geometry

- Single track study:
  - Autogeneous welds made on In625 “baseplate”
  - Weld width and estimated bead area measured
    - Width measured using a Taylor Hobson Form Talysurf PGI 1230 stylus profilometer and verified by Wyko white light interferometer to an accuracy of ±3µm
    - Area *estimated* from a scanning laser confocal microscope image of the weld tail; capturing the final melt pool as the laser is turned off

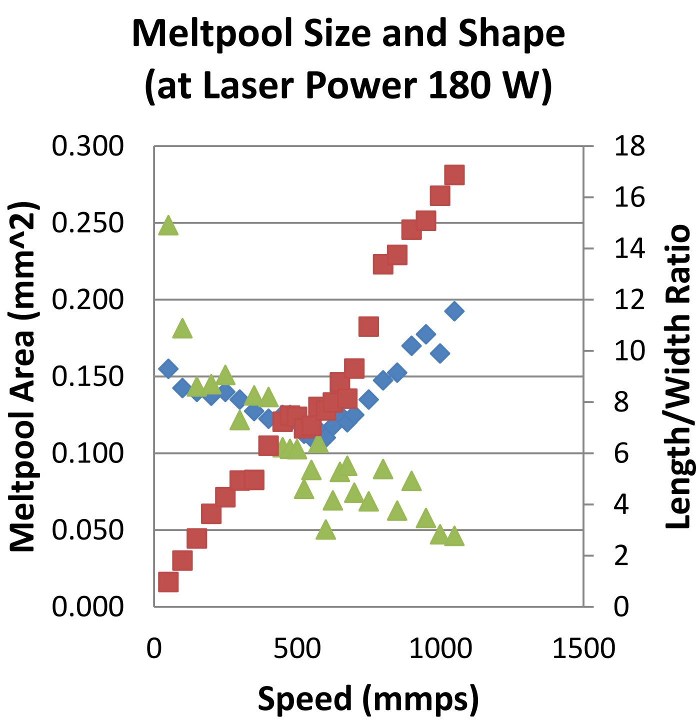


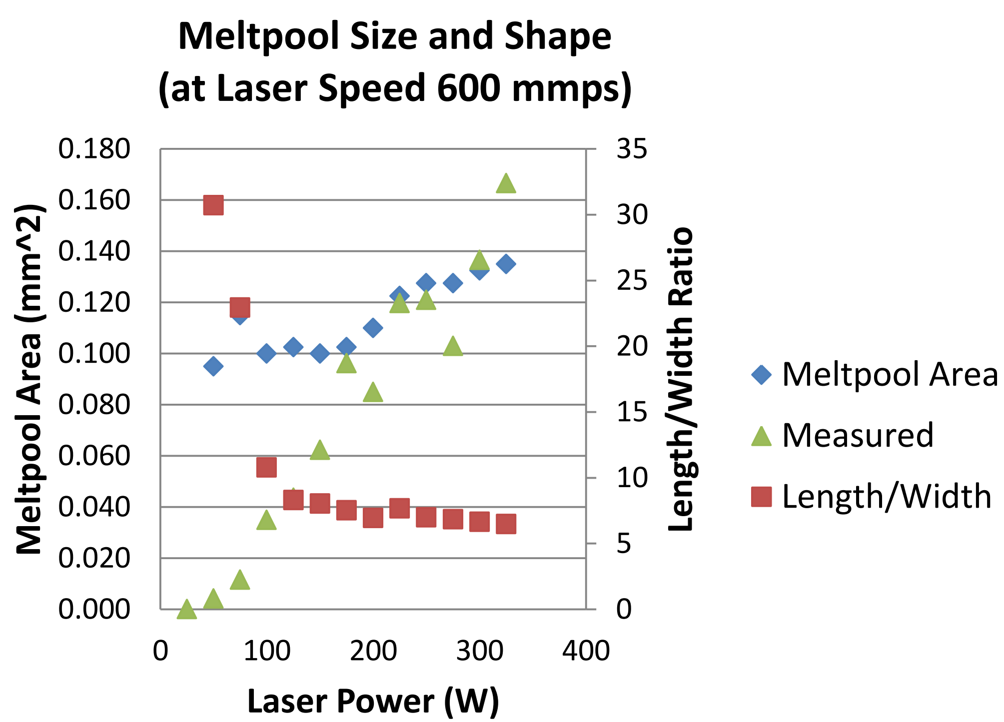




Melt Geometry Results

- Assuming a value of 0.0025 mm^2 per pixel, a melt area can be calculated
  - This area can be compared with the area estimates from microscope images
- Using this calculated area, and measured width, a L/W can be calculated

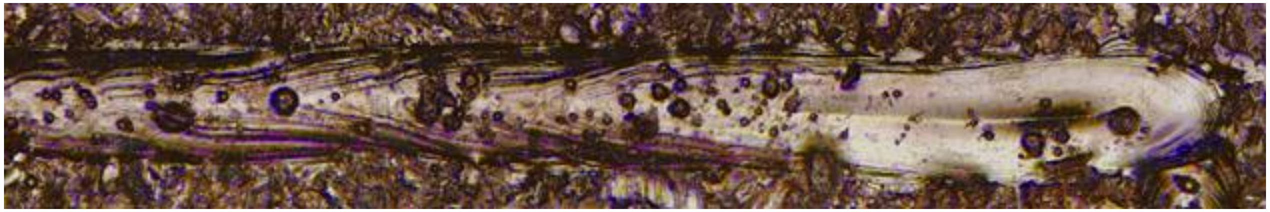




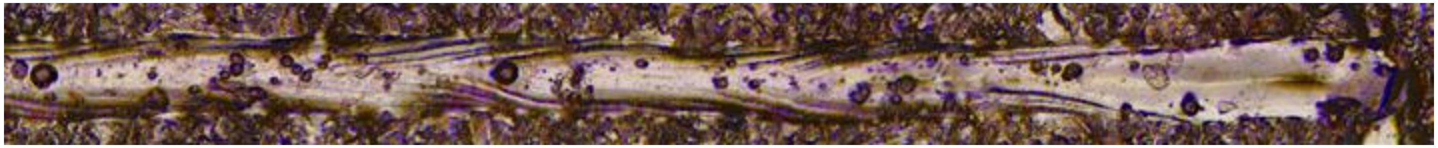
Application to Research

- Can observe trends in data to guide research
  - For example, clear transition region observed in graphs on previous chart; use this to guide hypotheses or observation of physical phenomena at this region
  - Before (100 mmps):

  - During (400 mmps):

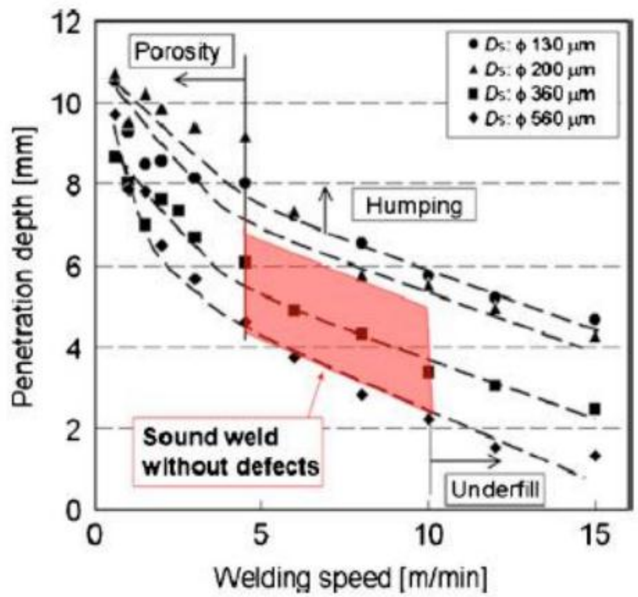


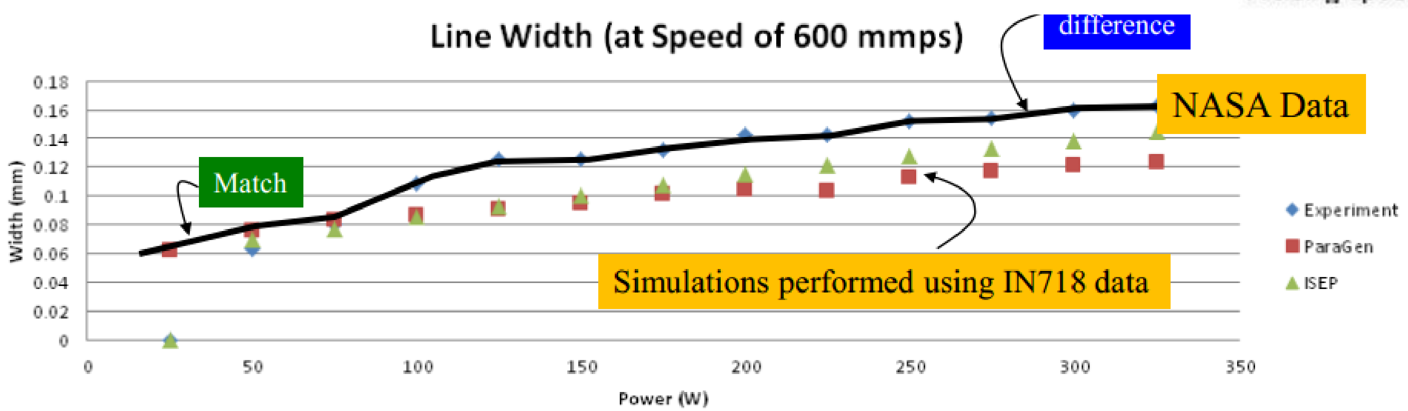
  - After (1000 mmps):



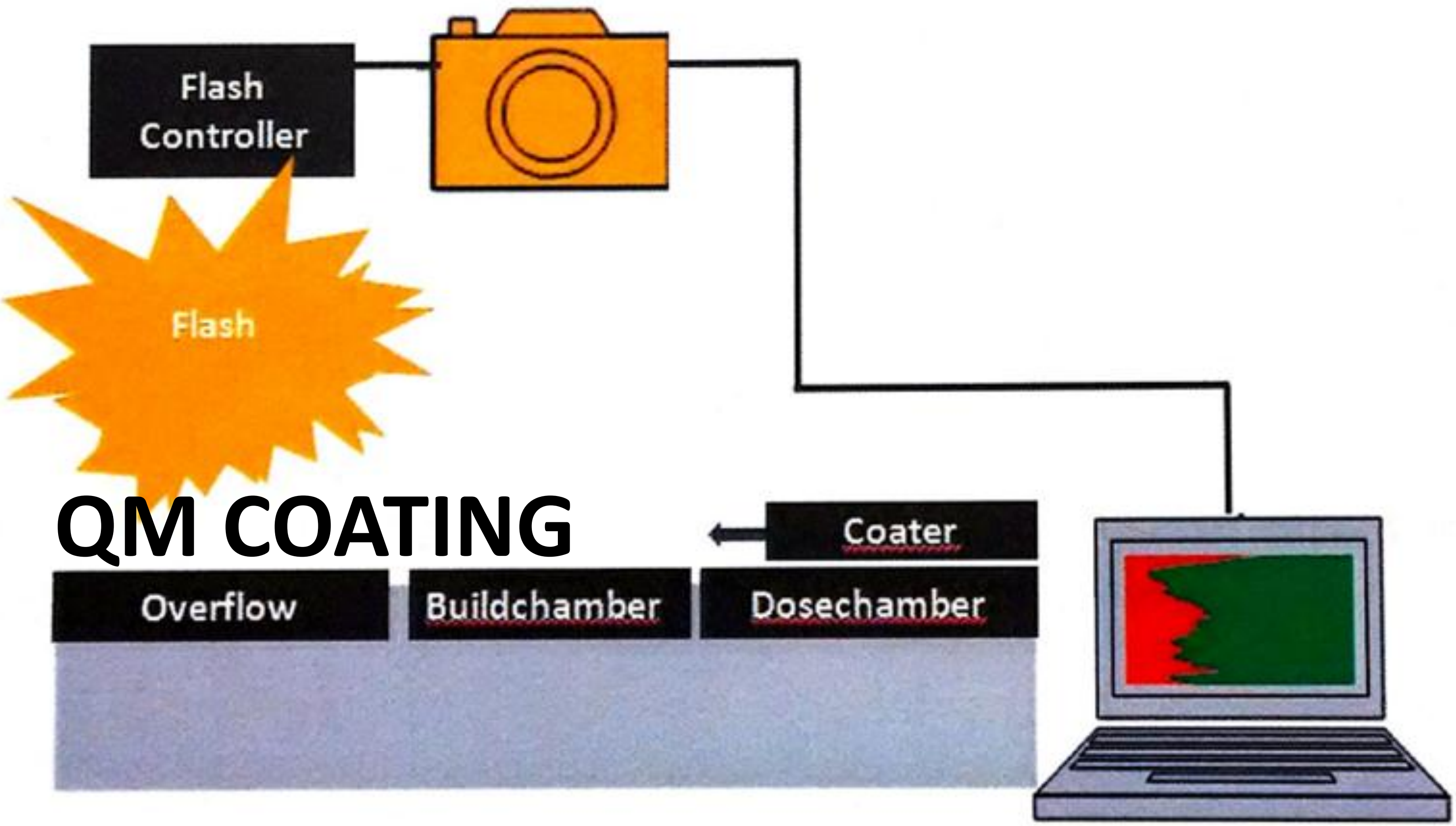
Application to Process Modeling

- Currently working with Applied Optimization (STTR), The Ohio State University (CIMJSEA), and internal code development (ER43) for powder-bed metals AM process modeling
  - Predict and offer solutions for defects





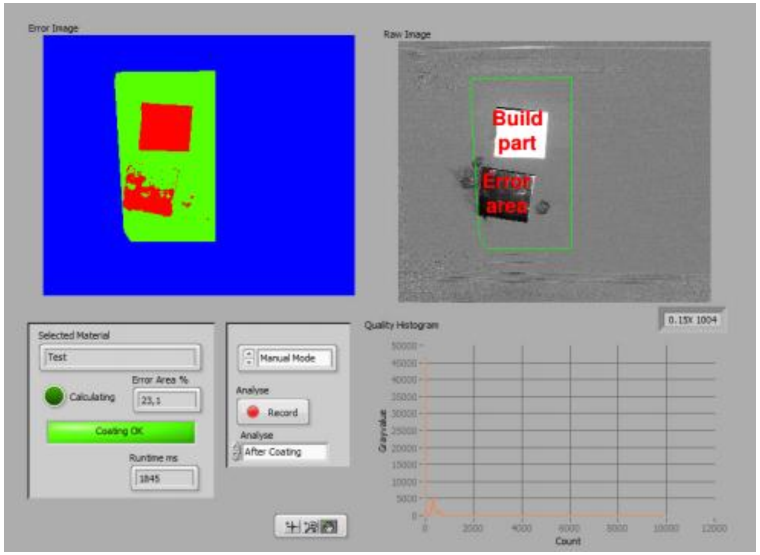
QM COATING



Flash
Controller
Flash
Coater
Overflow
Buildchamber
Dosechamber

System Description

- A high resolution camera captures optical images before and after each powder layer is applied. QM Coating software compares grayscale values in a user-defined region of interest to determine sufficient (green) or insufficient (red) coated areas. If enough area is deemed to be insufficiently coated, the layer is re-coated to eliminate short feeds
- User can save images for a record of the build

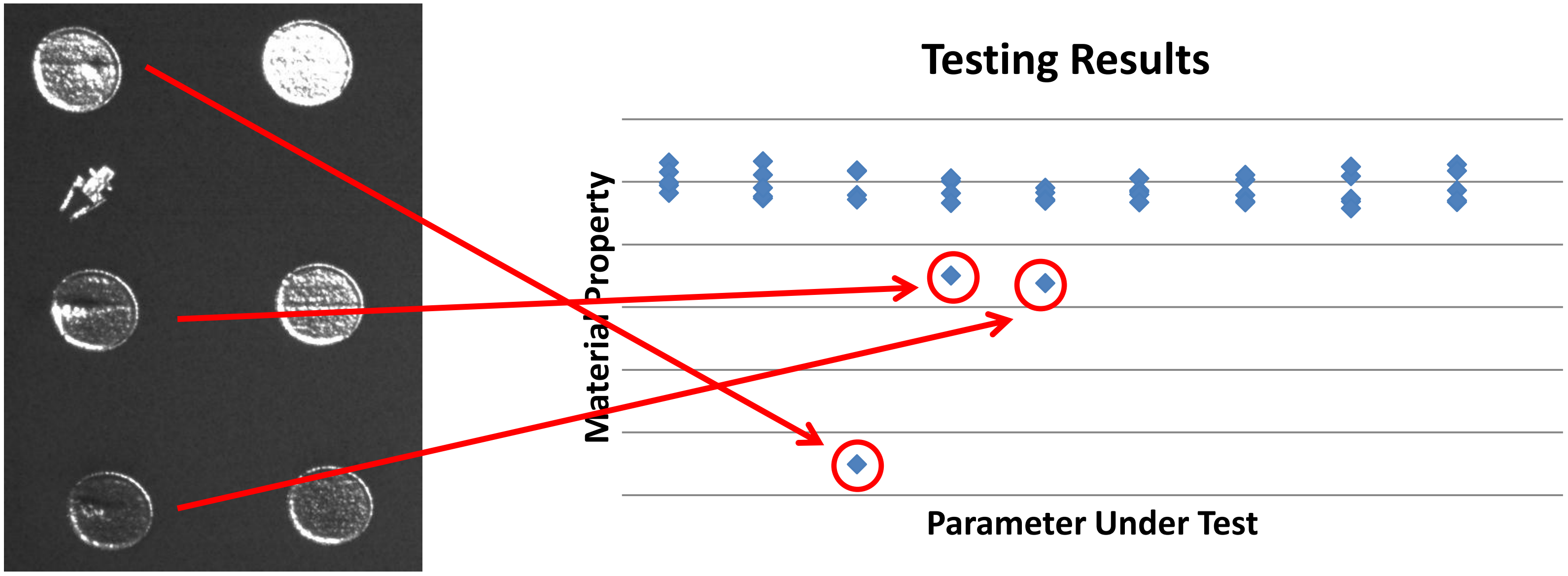


Use Description

- Marketed use is as a feedback-control system to operate autonomously during the build; e.g. recognize short feeds and correct the anomalies in-situ
- Potential NASA uses stem from the images providing a digital record of the build:
  - Documentation if required, or applied to a quality record
  - Non-destructive evaluation or failure analysis through layer-by-layer visual inspection
  - Internal or non-line-of sight geometry inspection (layer-by-layer)
    - Potential to develop software to reconstruct as-built geometry into a 3D model based on automatically determining the solidified material boundary in each layer

Application to NDE or Failure Analysis

- During build & test of ~50 tensile bars, engineers independently identified:
  - Anomalous tensile test results (→ failure analysis called for)
  - Defects observed in QM Coating images as tensile bars were printed (Visual inspection/NDE)



Conclusions

- QM Meltpool has been demonstrated to apply to NASA's uses in:
  - Research:
    - Can identify how input parameters change the size and shape of the melt pool
    - Can provide in-situ data to calibrate, and ultimately validate, process models
- Future investigations aim to justify QM Meltpool can apply to:
  - Process improvement
  - Qualification
- QM Coating has been demonstrated to apply to NASA's uses in:
  - Documentation, or applied to a quality record
  - Non-destructive evaluation
  - Failure analysis
- Future investigations aim to justify QM Coating can apply to:
  - As-built geometry reconstruction for internal or non-line-of-sight inspection

Questions?