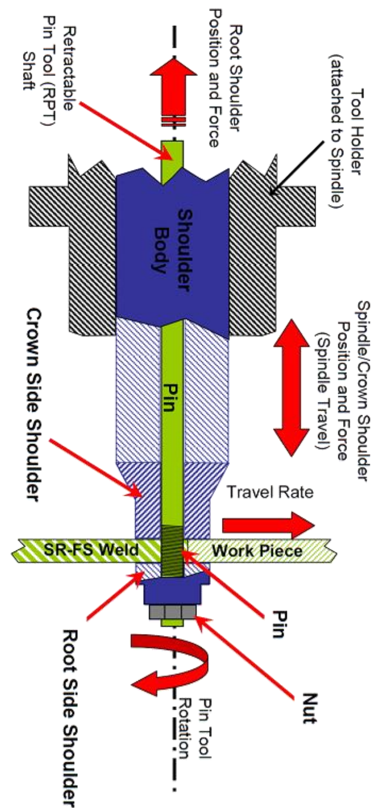
Improving Friction Stir Welding Reliability Through Machine Learning Control and Physics-Based Modeling

National Aeronautics and Space Administration

Dr. Paul W. C. Northrop[1,2,5], Anthony Maenza[1,3], Scott Tashakkor[1,4], Dr. Robert Amaro[1,2,5] , Jacob Anders[1,2]

[1]MSFC, [2]EM32, [3]ES52, [4]ES50 , [5]ESSCA

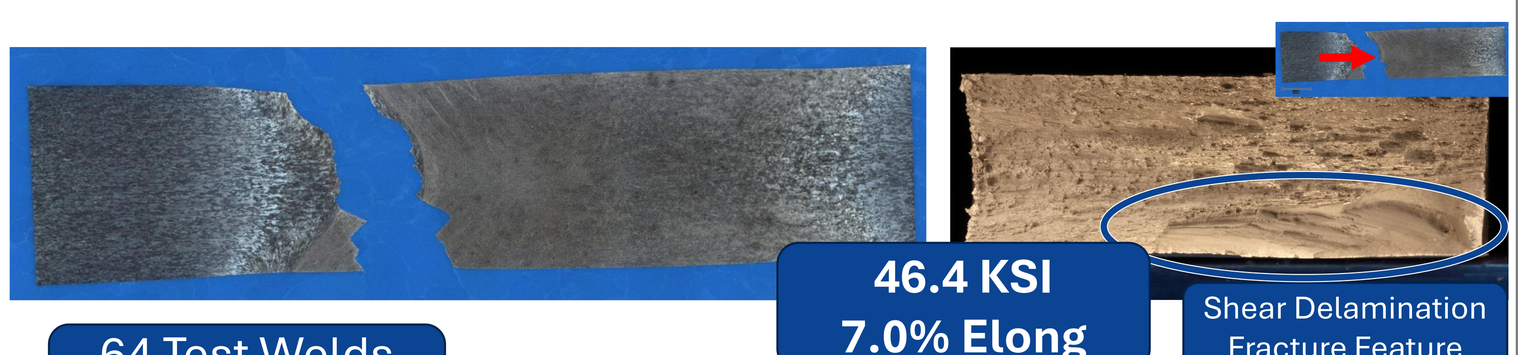
Self-Reacting Friction Stir Welding Background



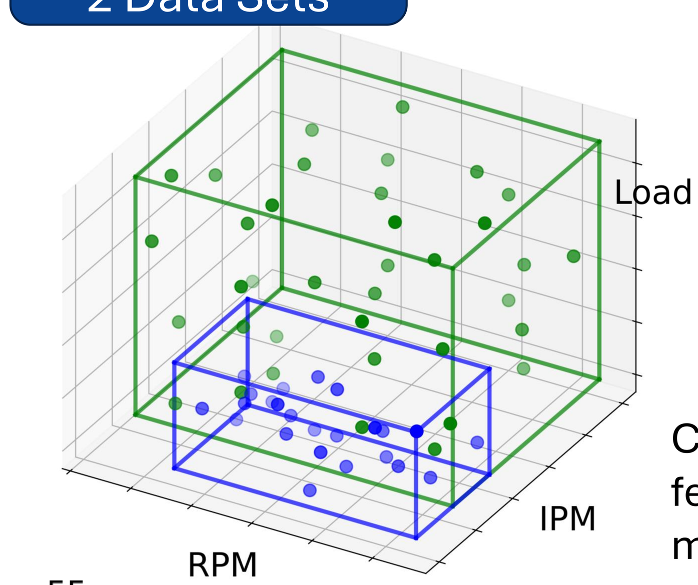
Anatomy of a Friction Stir Weld

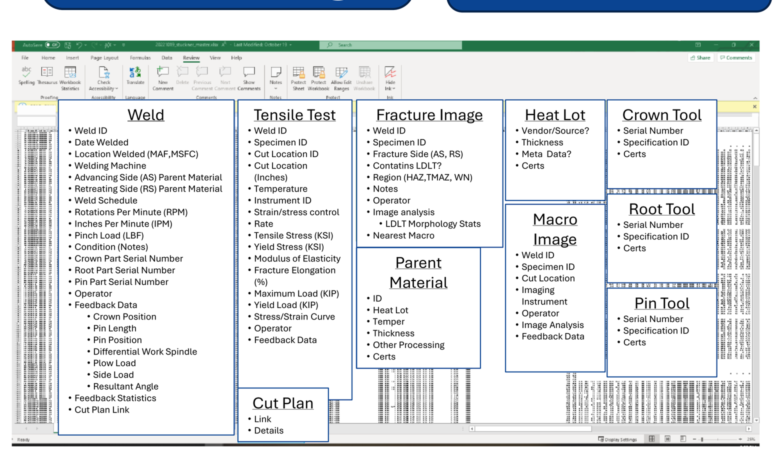
NESC/EM32 Joint Investigation Into Anomalous Welds

Acknowledgments: Ilana Lu, MSFC; Bob Carter, GRC; Dr. Josh Stuckner, GRC; Dr. Tony Reynolds, USC

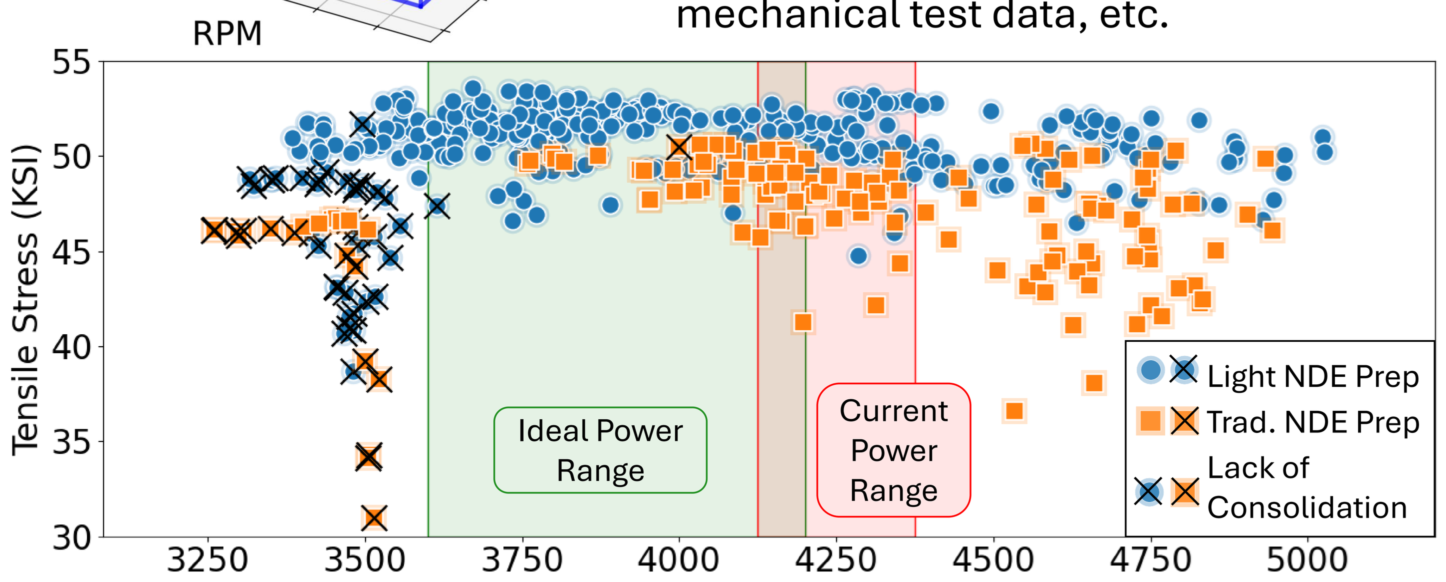


64 Test Welds
2 Data Sets





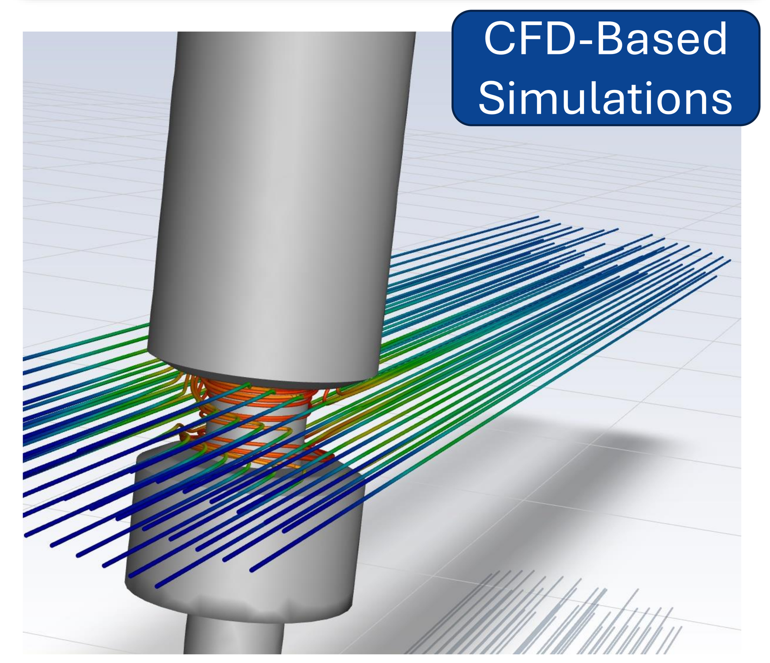
Copious data collected including weld feedback data, metallographic data, mechanical test data, etc.



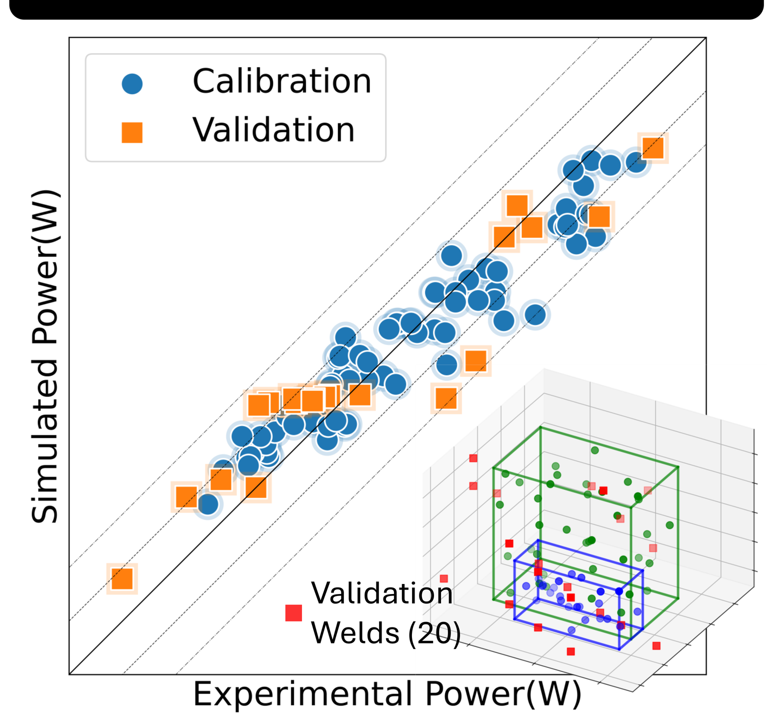
Conclusions

(1) Over preparation for NDE detrimental to strength.
(2) High or low power increases variability in weld strength

Physics-Based Modeling



Calibration and Validation

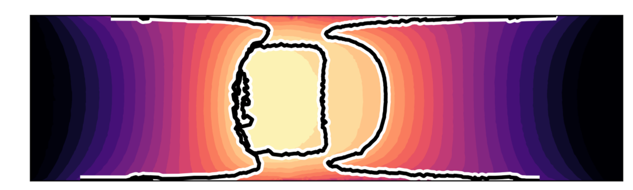


Predictions

Contour colors indicate maximum temperature.
Contour lines indicate high strain nugget region.

Small Weld Nugget

Lack of fusion behind tool → wormhole

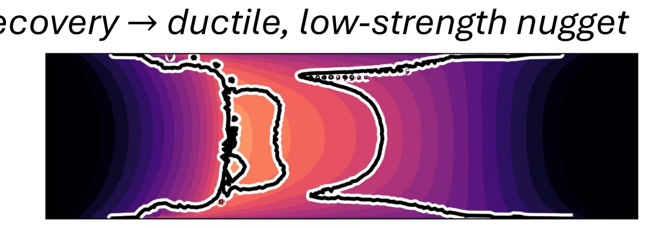


High Weld Temperature

Highly fluid nugget & overaging → shear delamination and mechanical variability

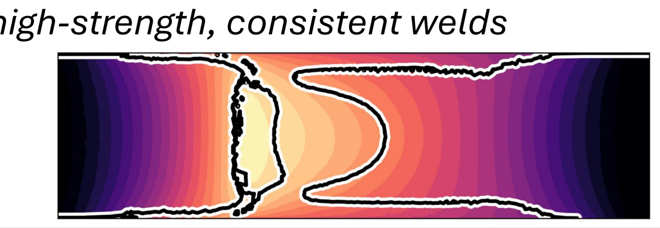
Low Weld Temperature

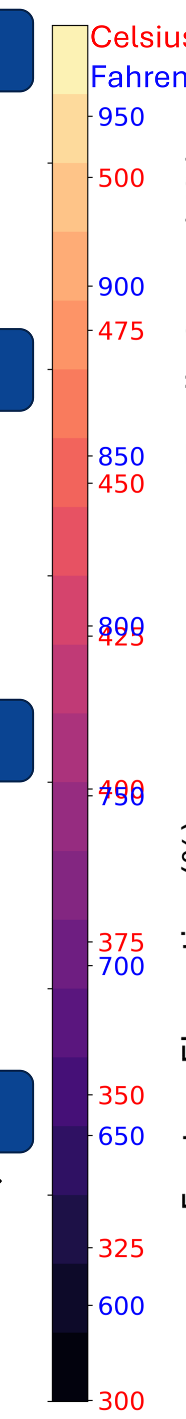
Favors θ-formation & minimal hardness recovery → ductile, low-strength nugget



Nominal Nugget

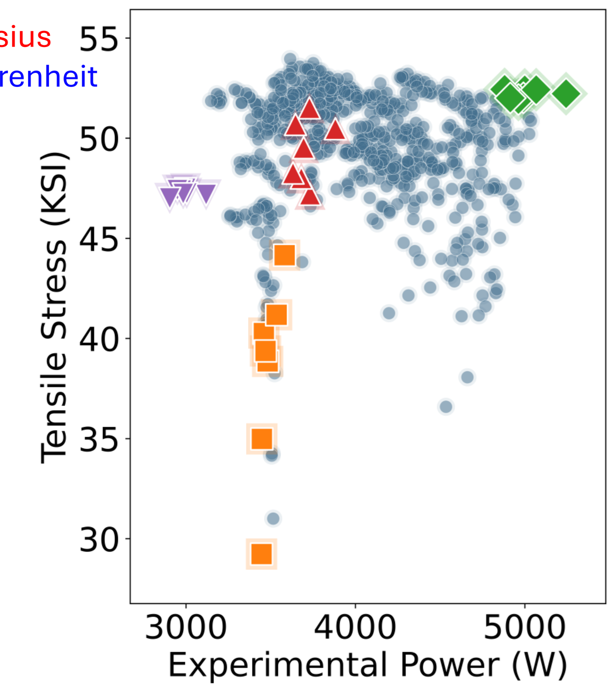
High IPM operation outside calibration→ *high-strength, consistent welds*

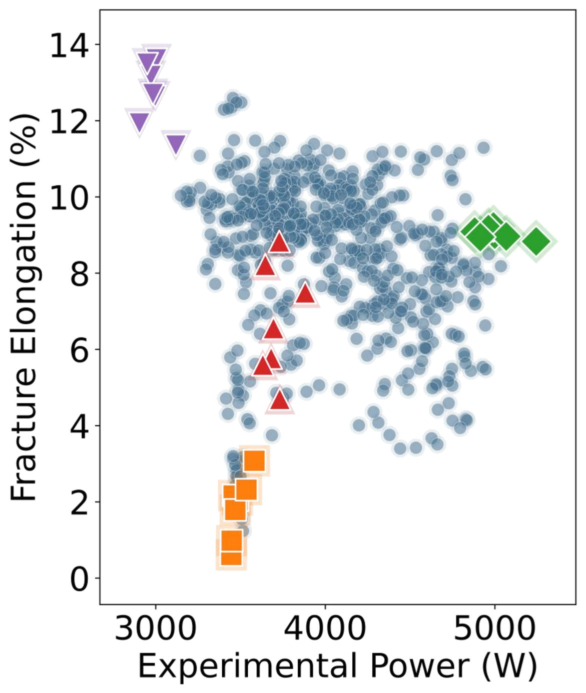


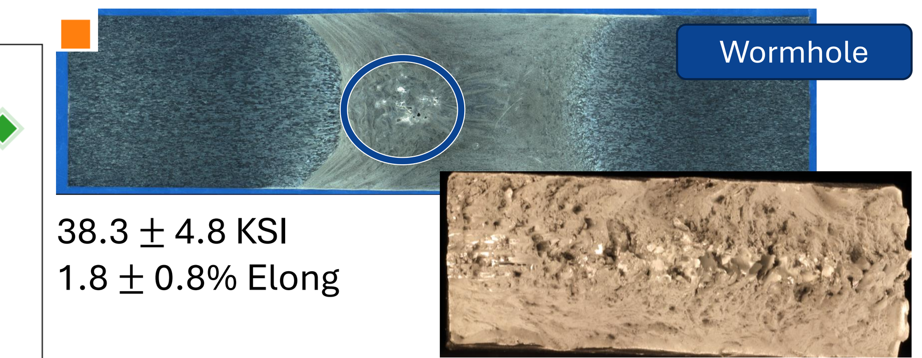


Welding Results

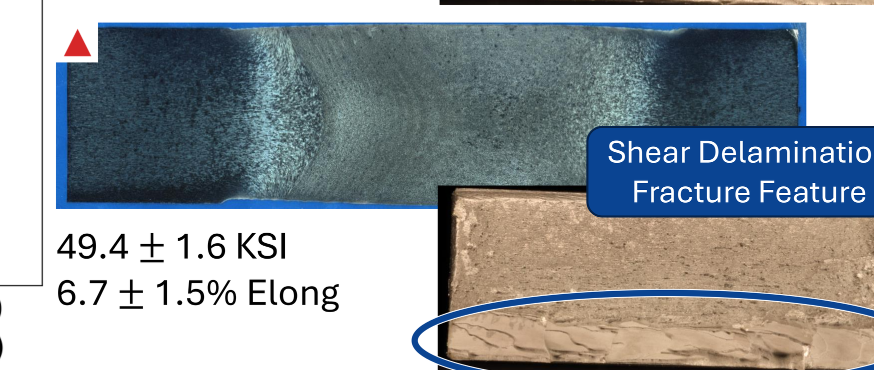
Metallographic Credits: Ben Rupp, MSFC; Sam McLeroy, MSFC (ESSCA)



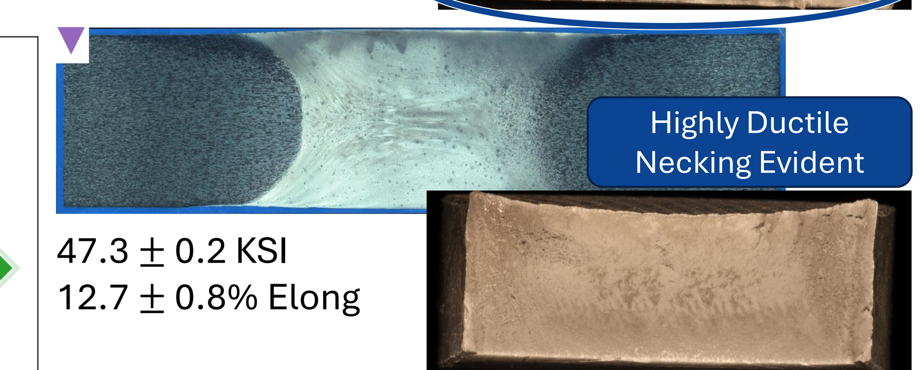




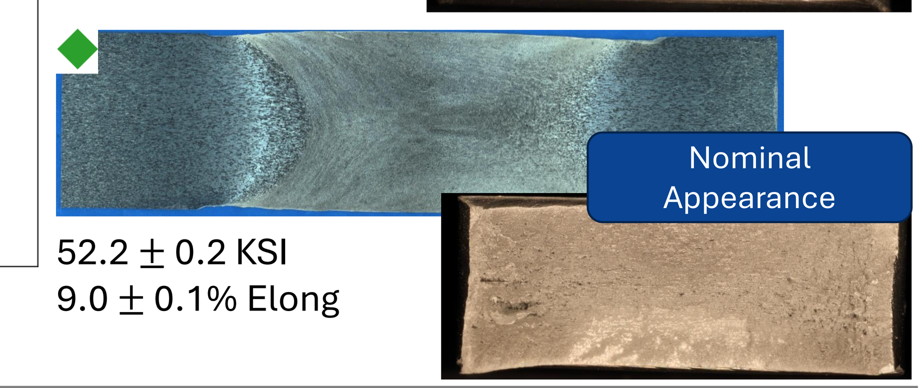
38.3 ± 4.8 KSI
1.8 ± 0.8% Elong



49.4 ± 1.6 KSI
6.7 ± 1.5% Elong



47.3 ± 0.2 KSI
12.7 ± 0.8% Elong



52.2 ± 0.2 KSI
9.0 ± 0.1% Elong

Machine Learning Control

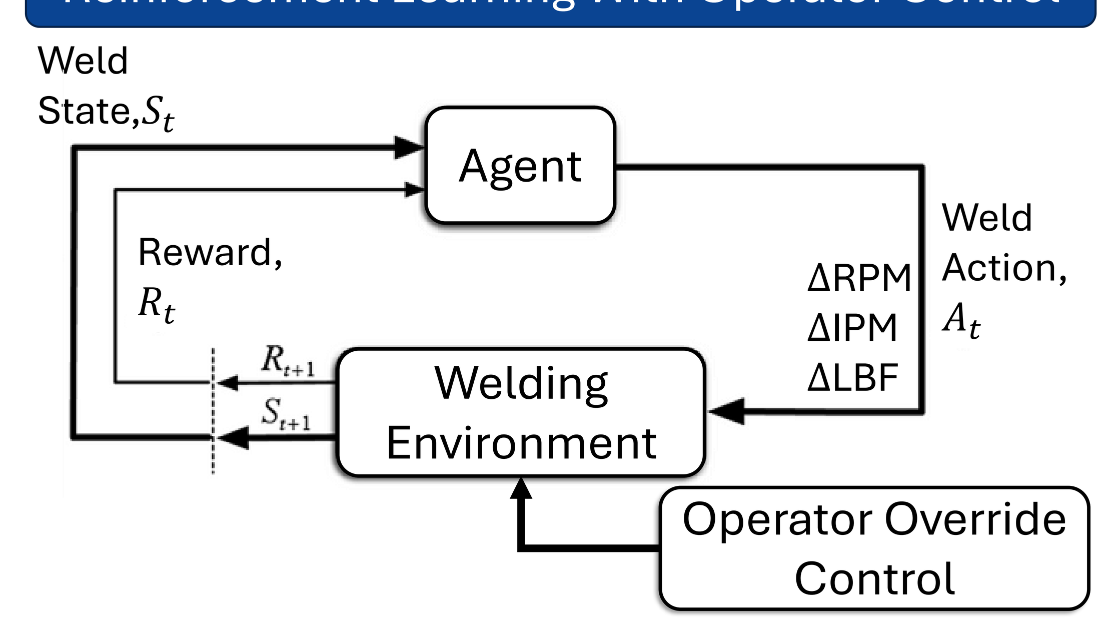
Adaptability

Maximize responsiveness and maintain control in response to *in situ* and *ex situ* process disturbances.

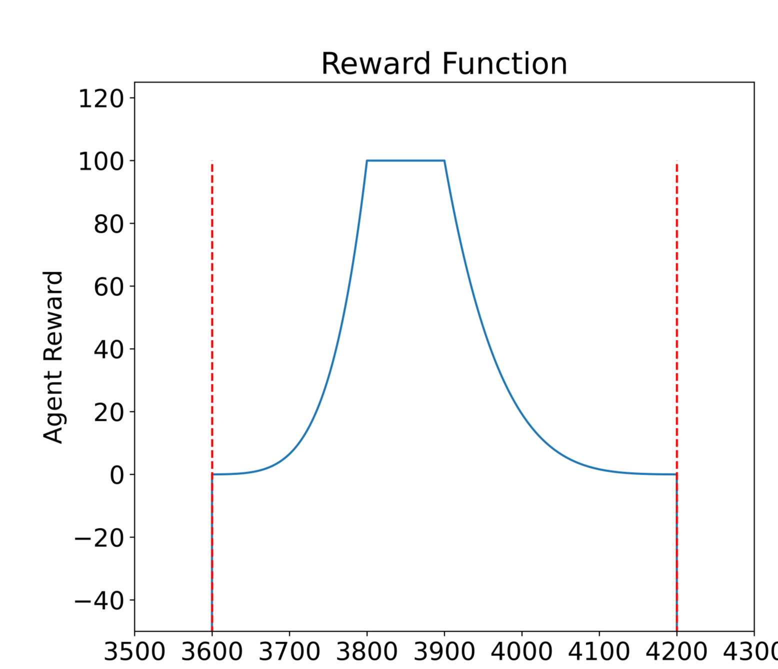
Flexibility

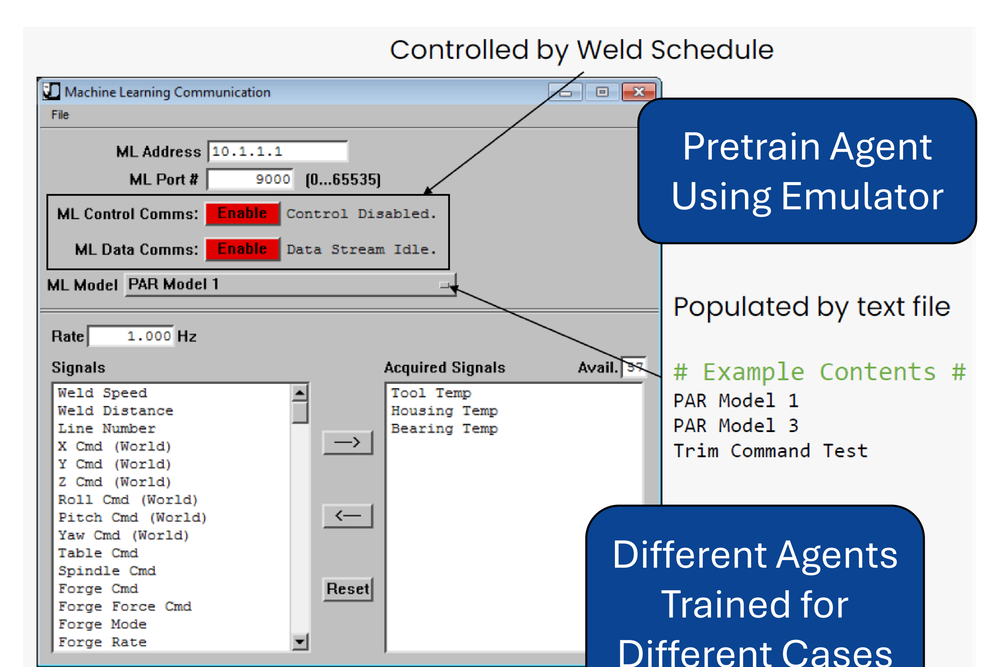
Incorporate new discoveries to optimize control strategy to maximize weld performance.

Reinforcement Learning With Operator Control



Implementation on Welding Systems





Preliminary AI/ML Welding Results