Friction Stir Process Mapping Methodology

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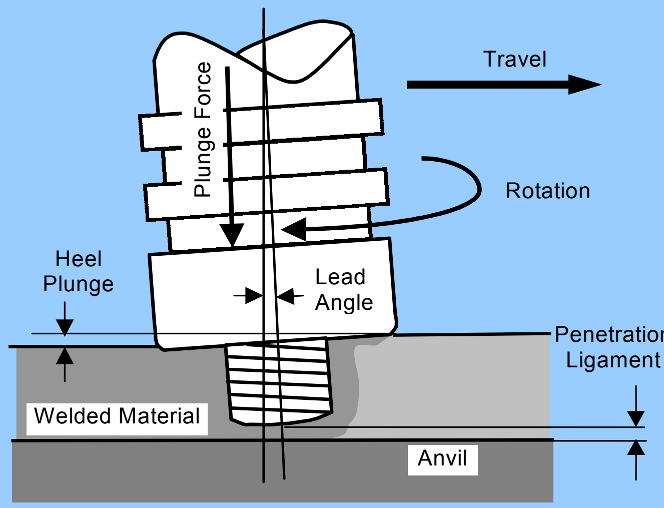
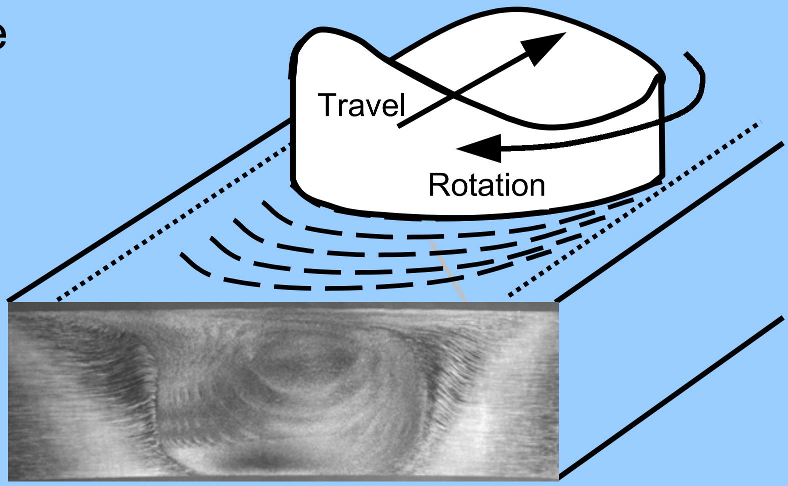
Process Overview

LOCKHEED MARTIN

- Friction Stir Welding (FSW)
  - FSW is a solid-state process using a rotating tool with a shoulder and a projecting pin.
  - The pin tool is rotated and plunged into the joint until the shoulder contacts the top surface.
  - The frictional heating between the pin tool and the joint plasticizes the material in the local region near the pin.
  - The material at the weld centerline is joined through a combination of forging processes that occurs in the local region of the pin tool.
  - Three significant parameters: spindle speed, travel speed, plunge load or plunge position

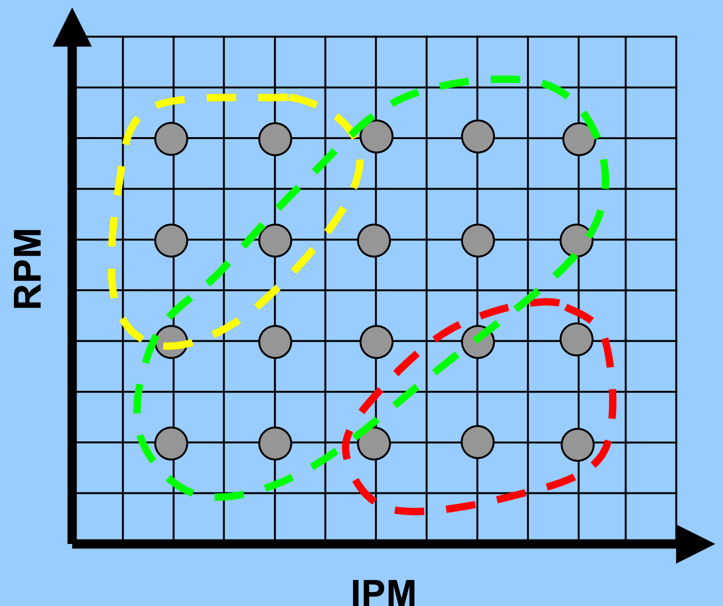




FSW Process Maps

LOCKHEED MARTIN

- A process map summarizes the weld process performance for a given pin tool geometry and joint configuration.
- Targeting a consistent penetration ligament, the process is simplified into two parameters: travel speed and rotation speed.
- Other parameters, such as plunge force, traverse force, weld nugget geometry, NDE response, and mechanical properties are assumed to be dependent variables.

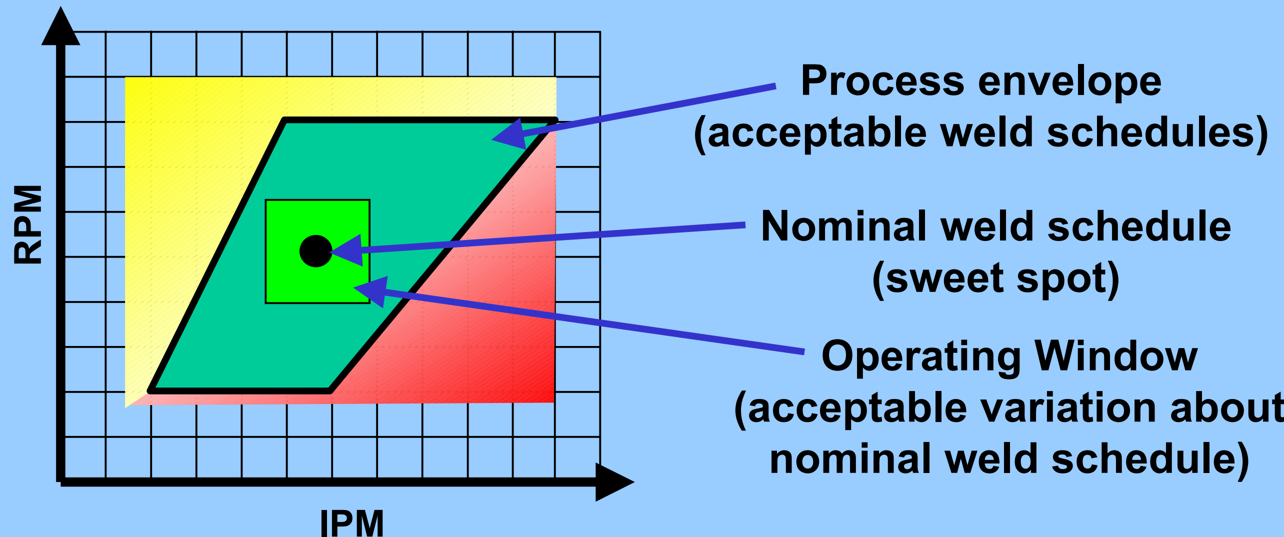


- **YELLOW:** Unusual flow patterns, unstable position and process loads, excessive flash, poor mechanical properties
- **GREEN:** Symmetric flow patterns, stable position and process loads, good strength
- **RED:** NDE rejections, volumetric defects, poor strength, excessive process loads

FSW Process Maps

LOCKHEED MARTIN

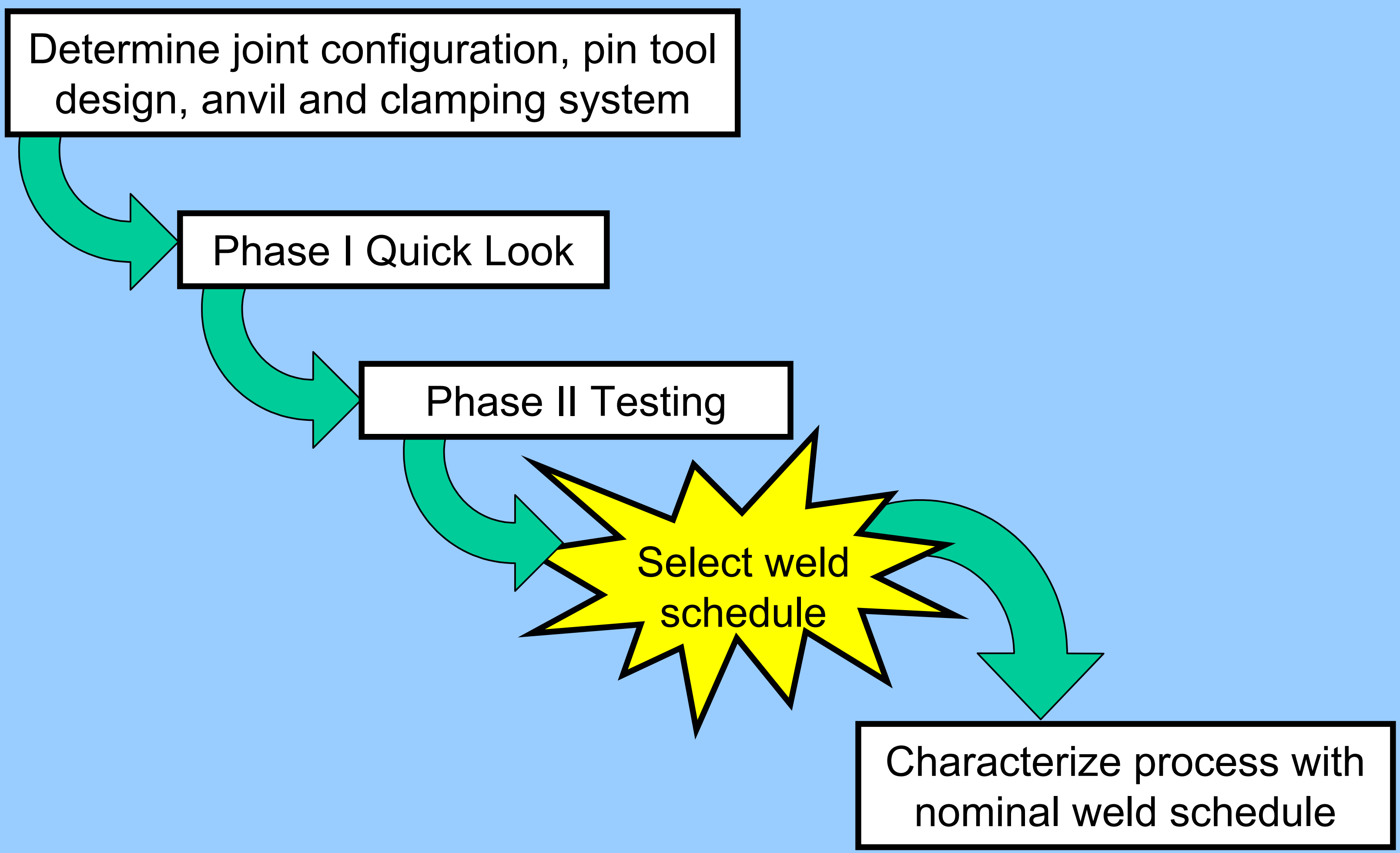
- A selected rpm/ipm combination (weld schedule) provides a specific nugget geometry, heat input, and mechanical strength.
- The selected nominal weld schedule, or sweet spot, is the best compromise between process stability, mechanical strength, NDE response, and machine capability.
- Once the nominal schedule is selected, process loads and heel positions are explored to determine their acceptable operating windows.
- Statistical process control in conjunction with the process map data provides quality control and grounds for reduced NDE requirements.



FSW Process Maps

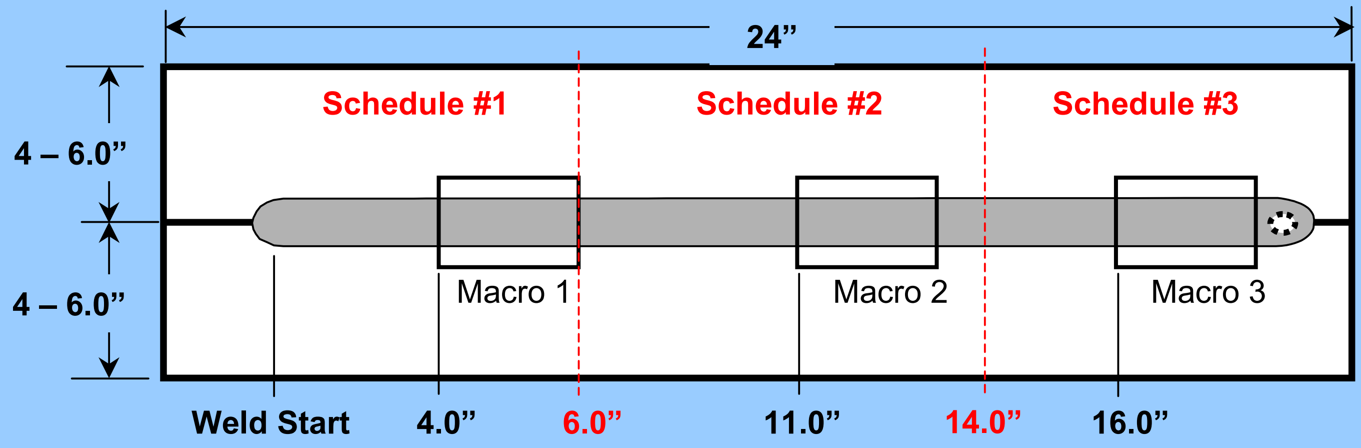
LOCKHEED MARTIN

- Methodology Overview



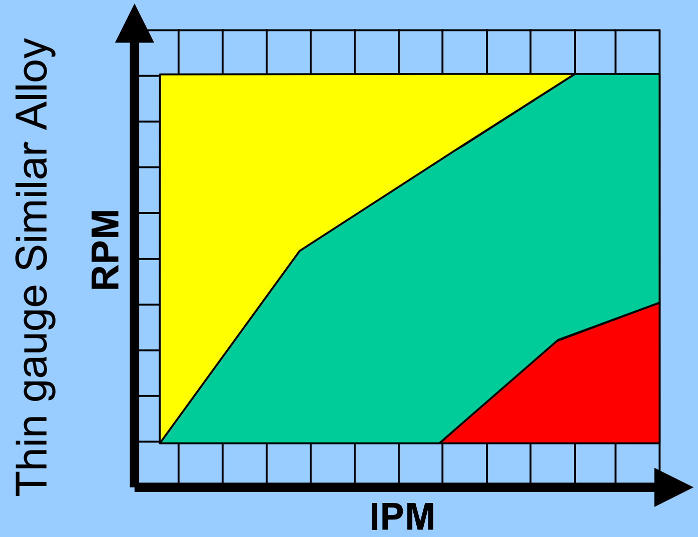
Phase I Quick Look

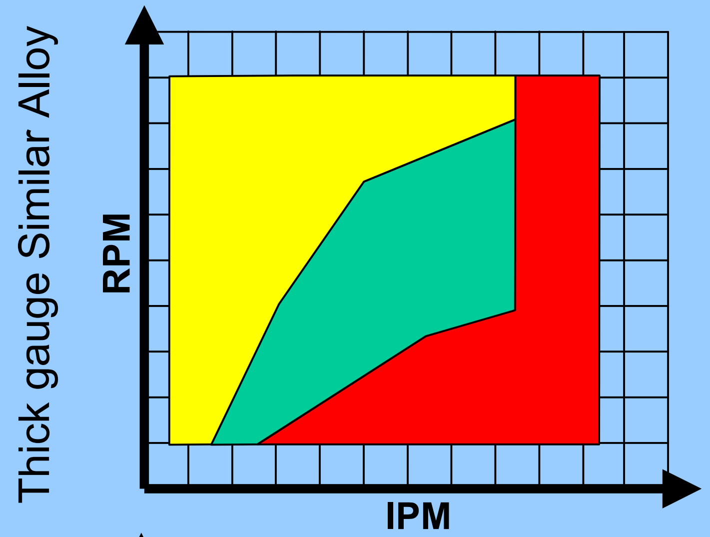
- The "quick look" provides a general overview of the process map
  - Three weld schedules are performed on a 24 inch long test panel
  - Weld schedules are performed "hot" to "cold" by changing the travel speed (constant rotation speed)
  - Metallographic samples are excised near the end of each weld schedule

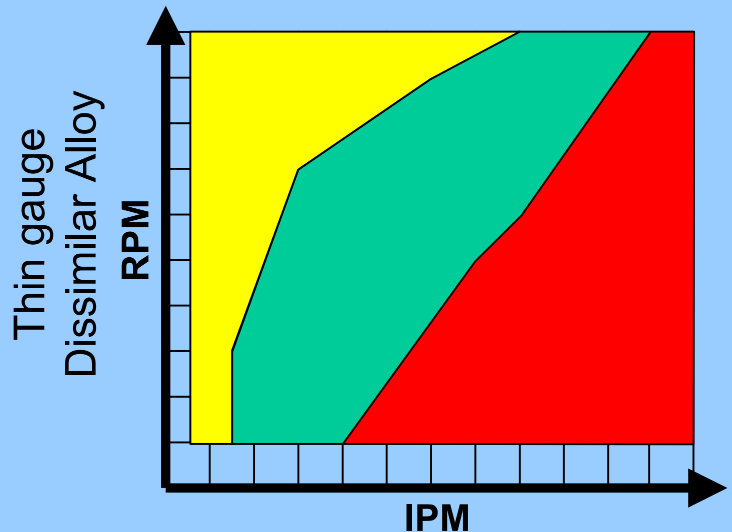


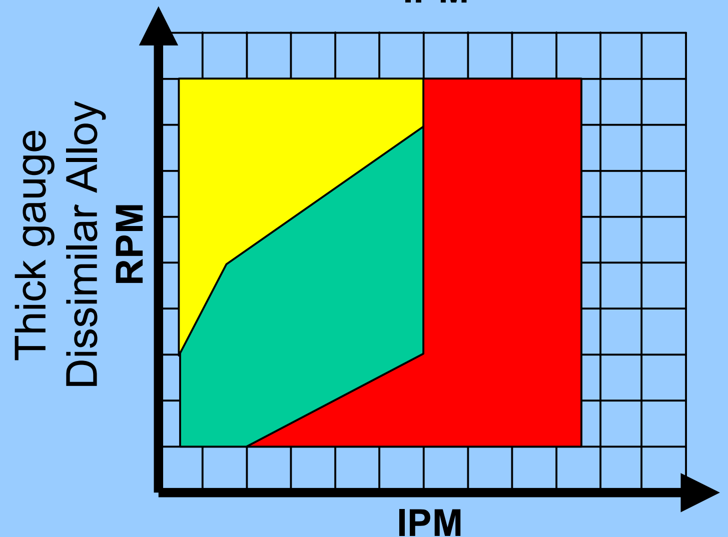
Phase I Quick Look

- Yellow, Green, and Red regions are delineated based on the metallographic data from the Quick Look welds.





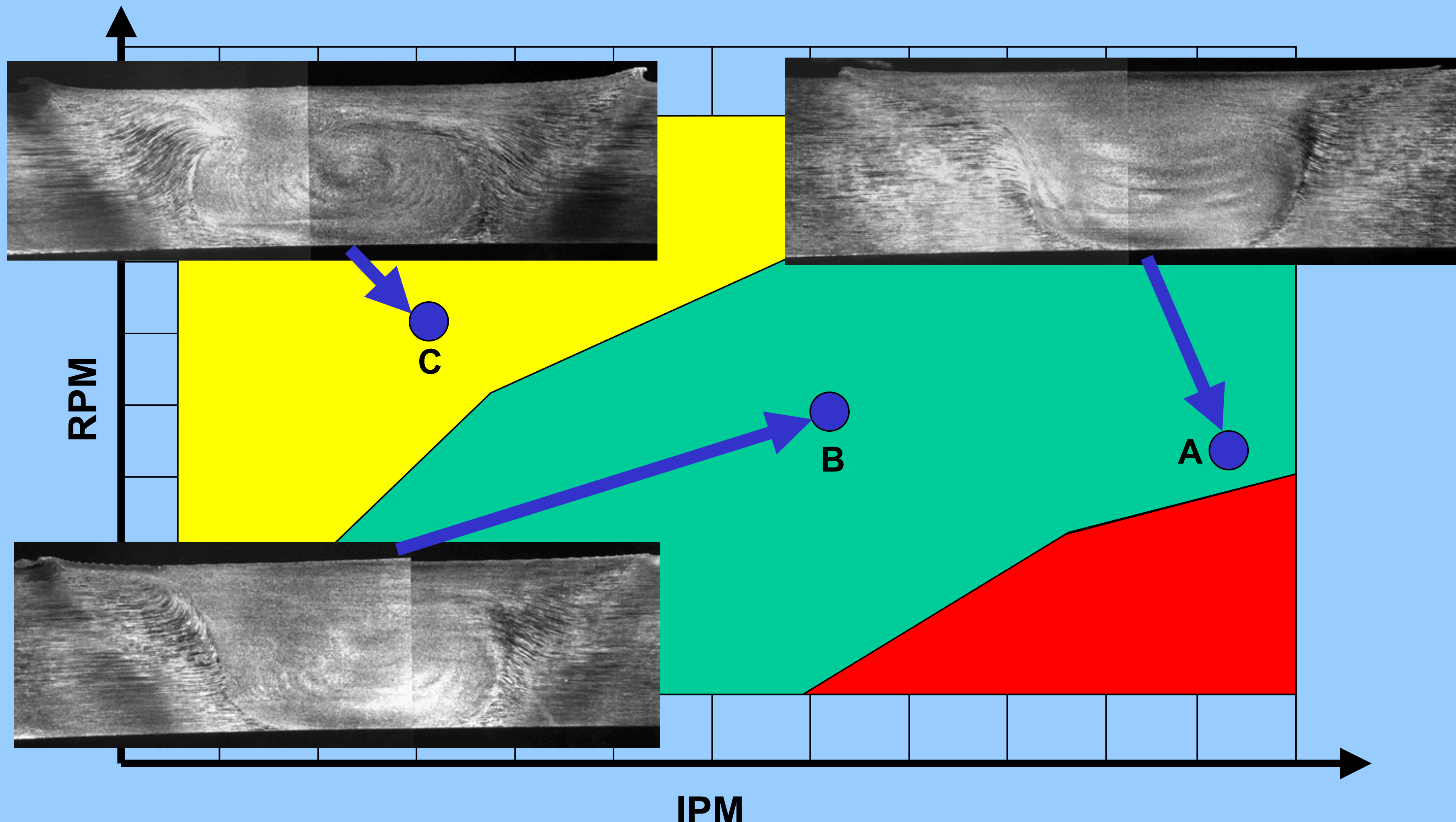




Phase I Quick Look

LOCKHEED MARTIN

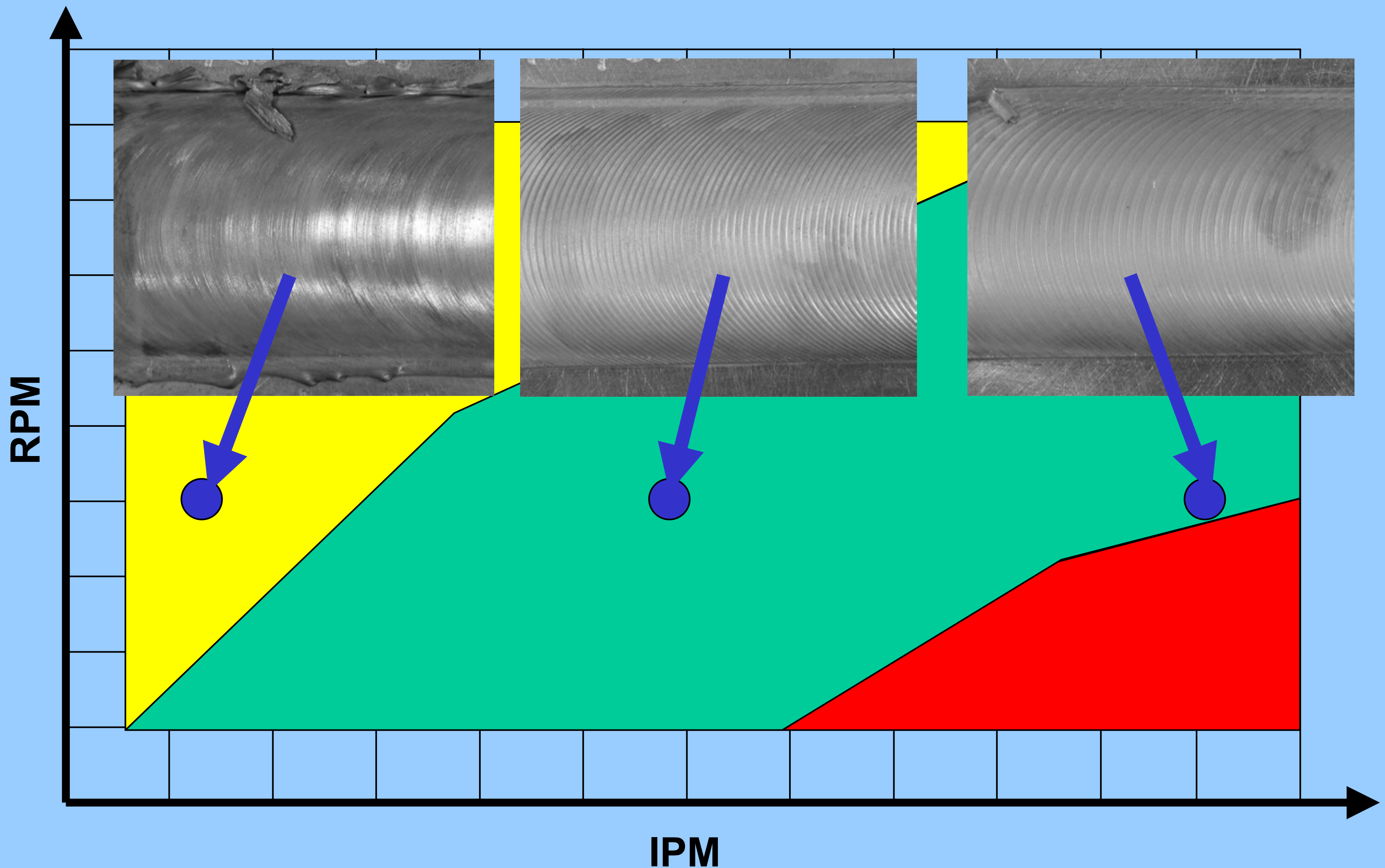
- Thin gauge similar alloy configuration
  - **Low (A), medium (B), and high (C) heat input**



Phase I Quick Look

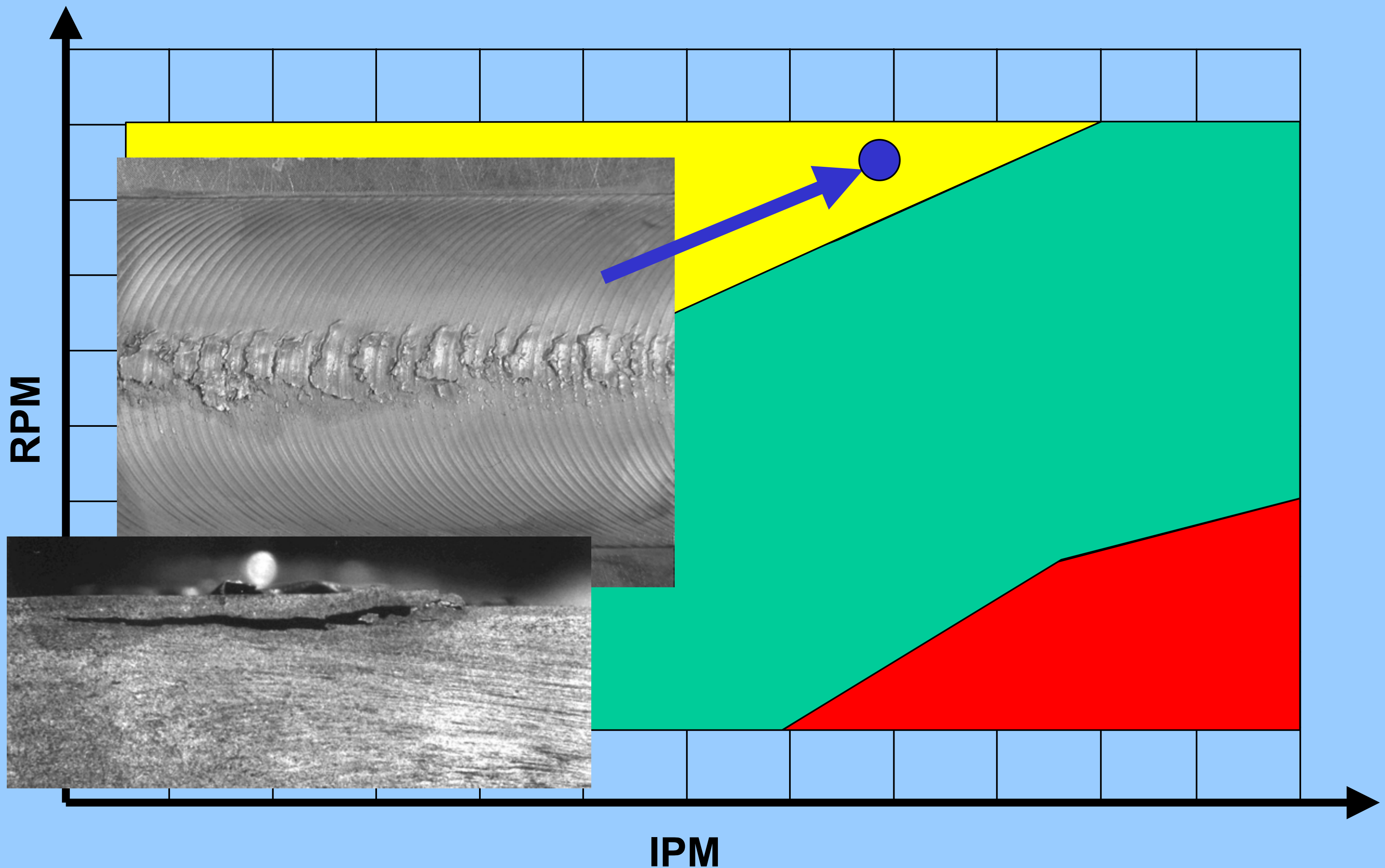
LOCKHEED MARTIN

- Thin gauge similar alloy configuration
  - Heel plunge vs. travel rate



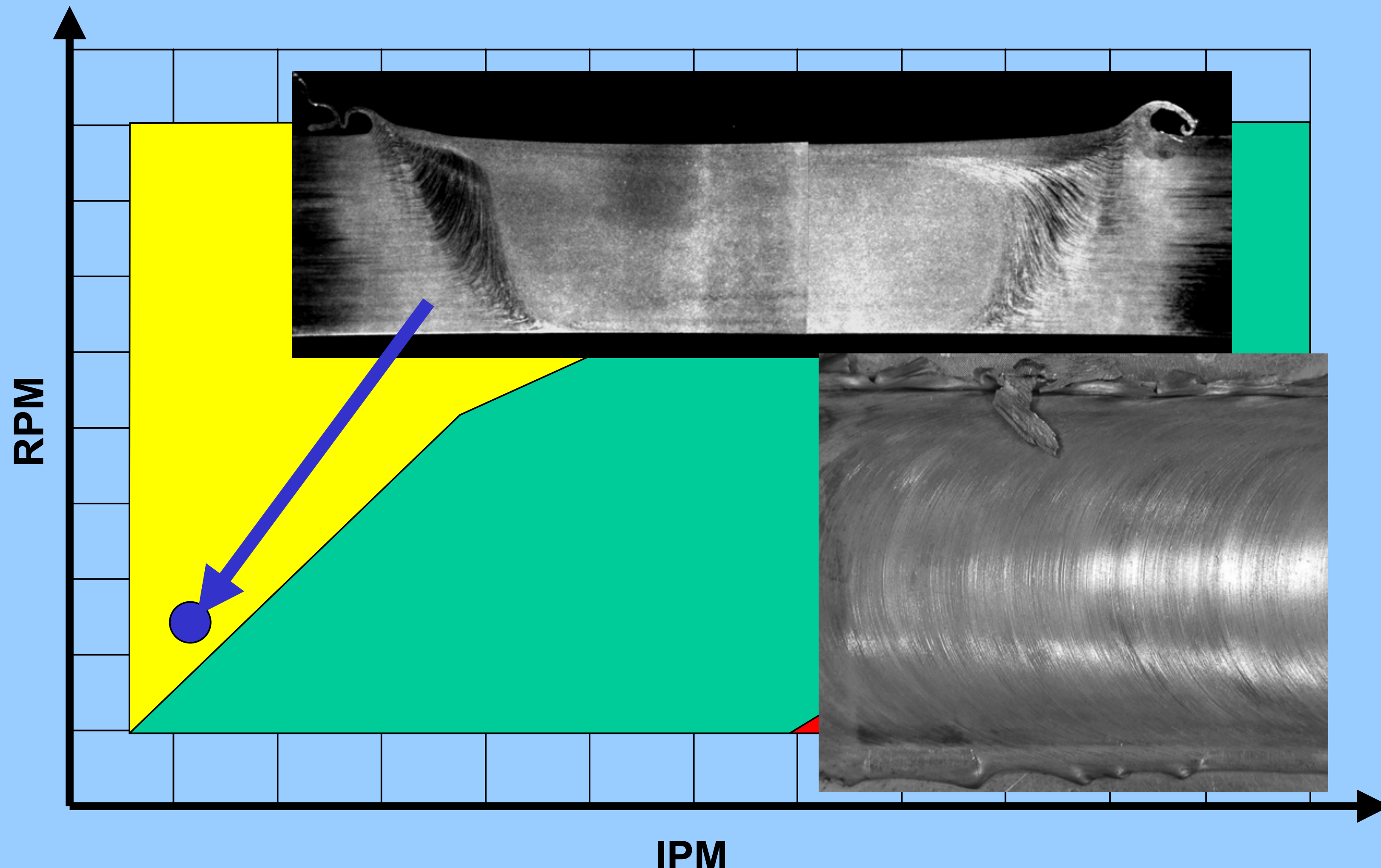
Phase I Quick Look

- Thin gauge similar alloy configuration
  - Scaling/ Galling



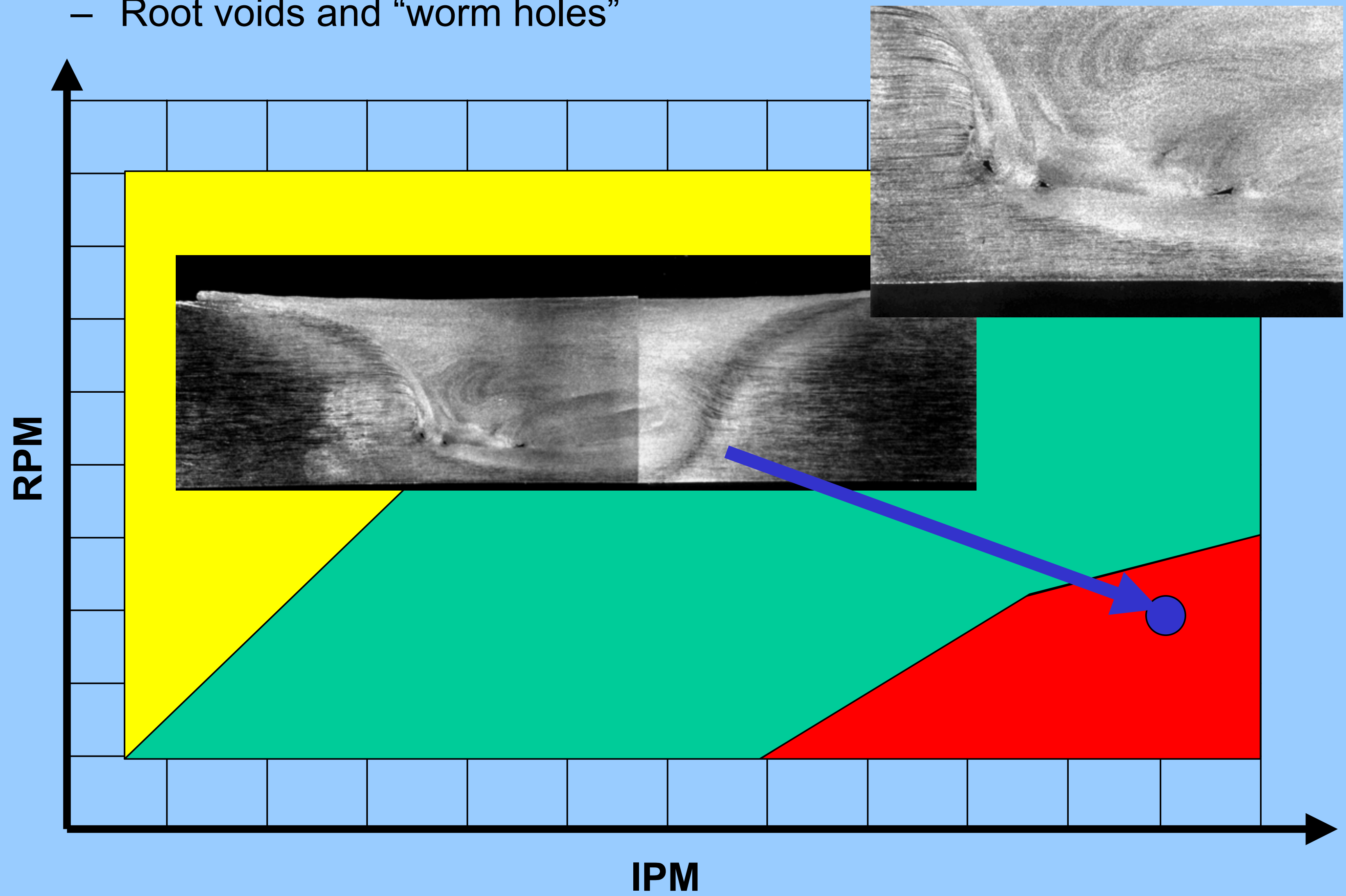
Phase I Quick Look

- Thin gauge similar alloy configuration
  - Large Weld Nugget and Excessive Flash



Phase I Quick Look

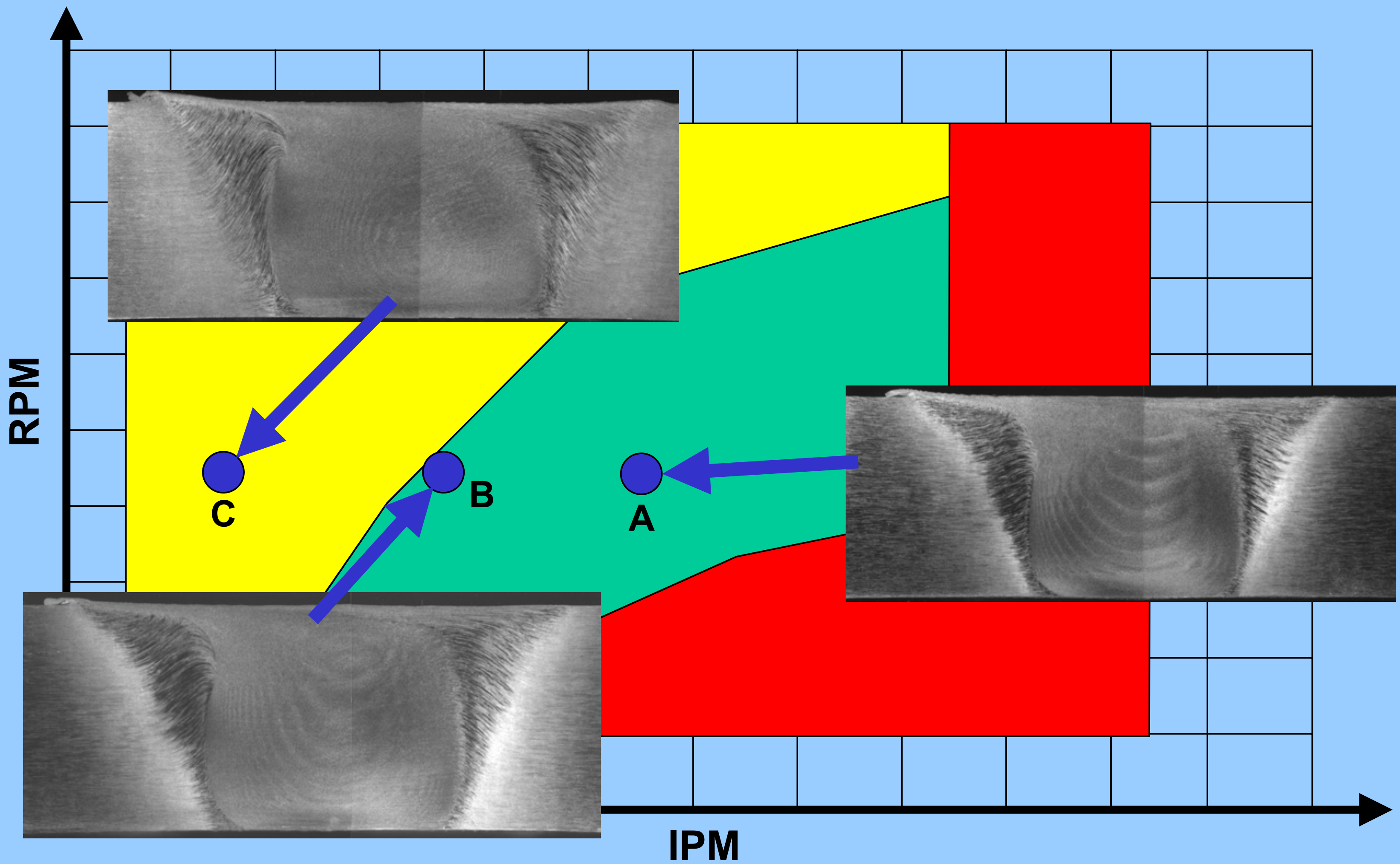
- Thin gauge similar alloy configuration
  - Root voids and “worm holes”



Phase I Quick Look

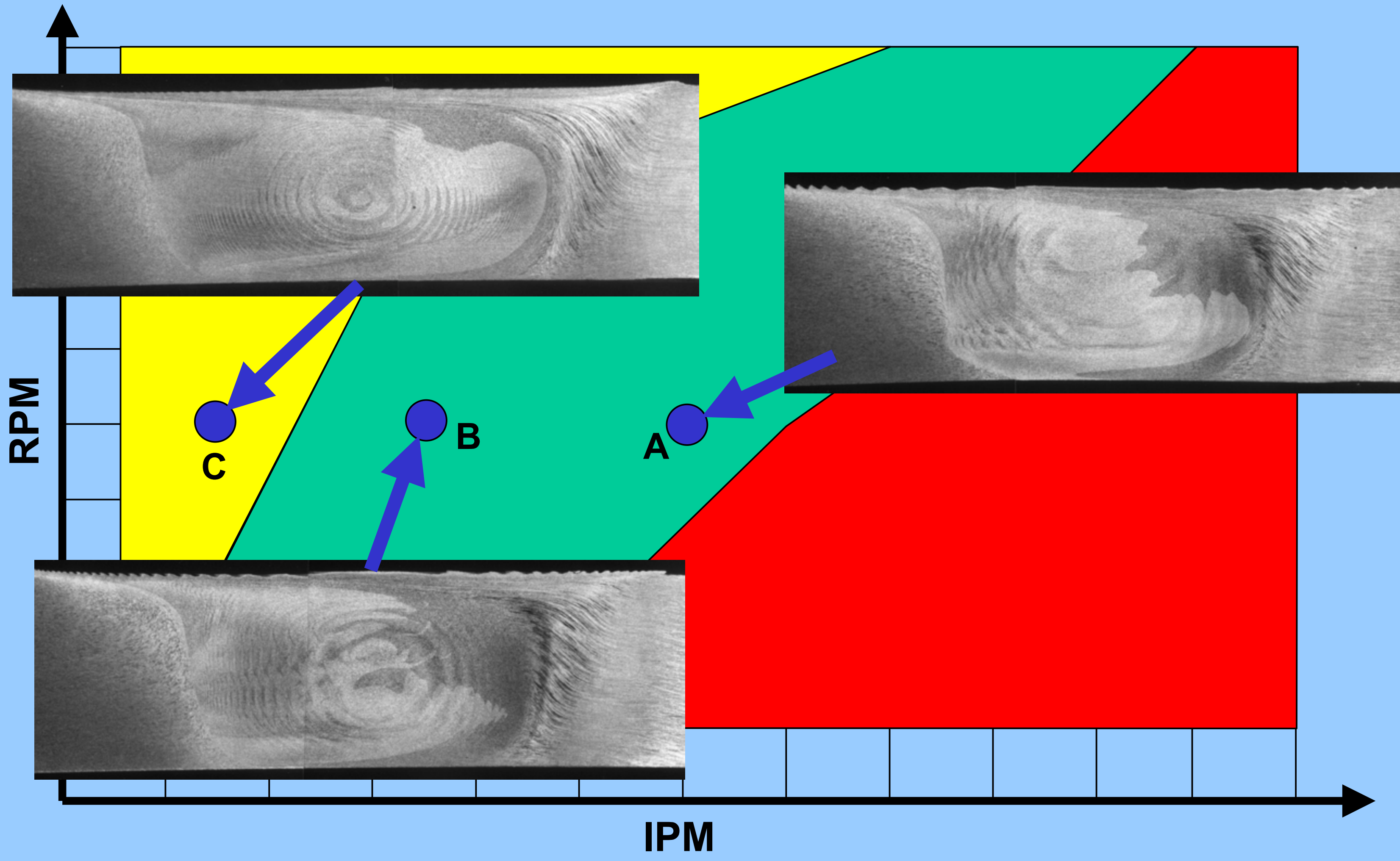
LOCKHEED MARTIN

- Thick gauge similar alloy configuration
  - Low (A), medium (B), and high (C) heat input



Phase I Quick Look

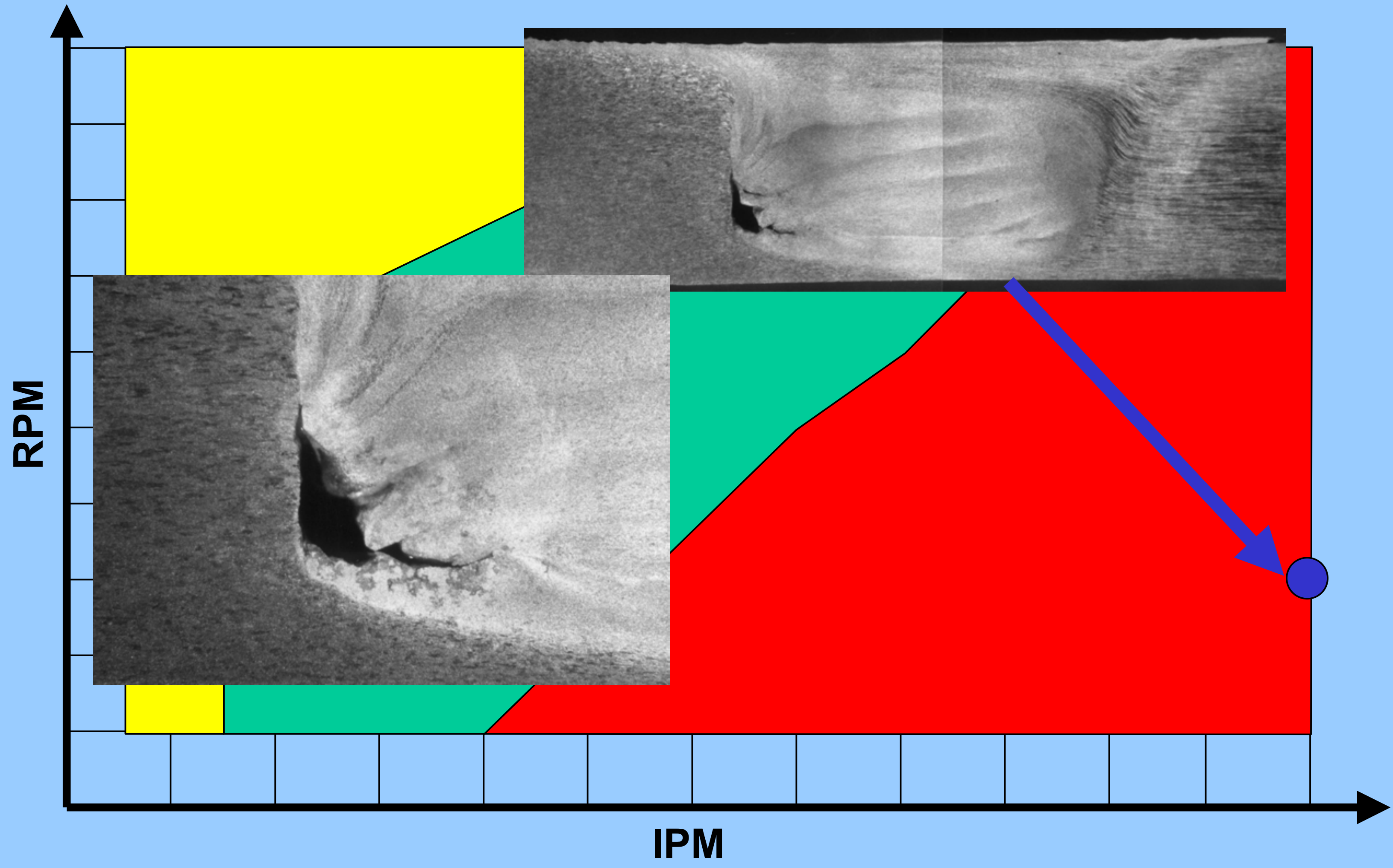
- Thin gauge dissimilar alloy configuration
  - Low (A), medium (B), and high (C) heat input



Phase I Quick Look

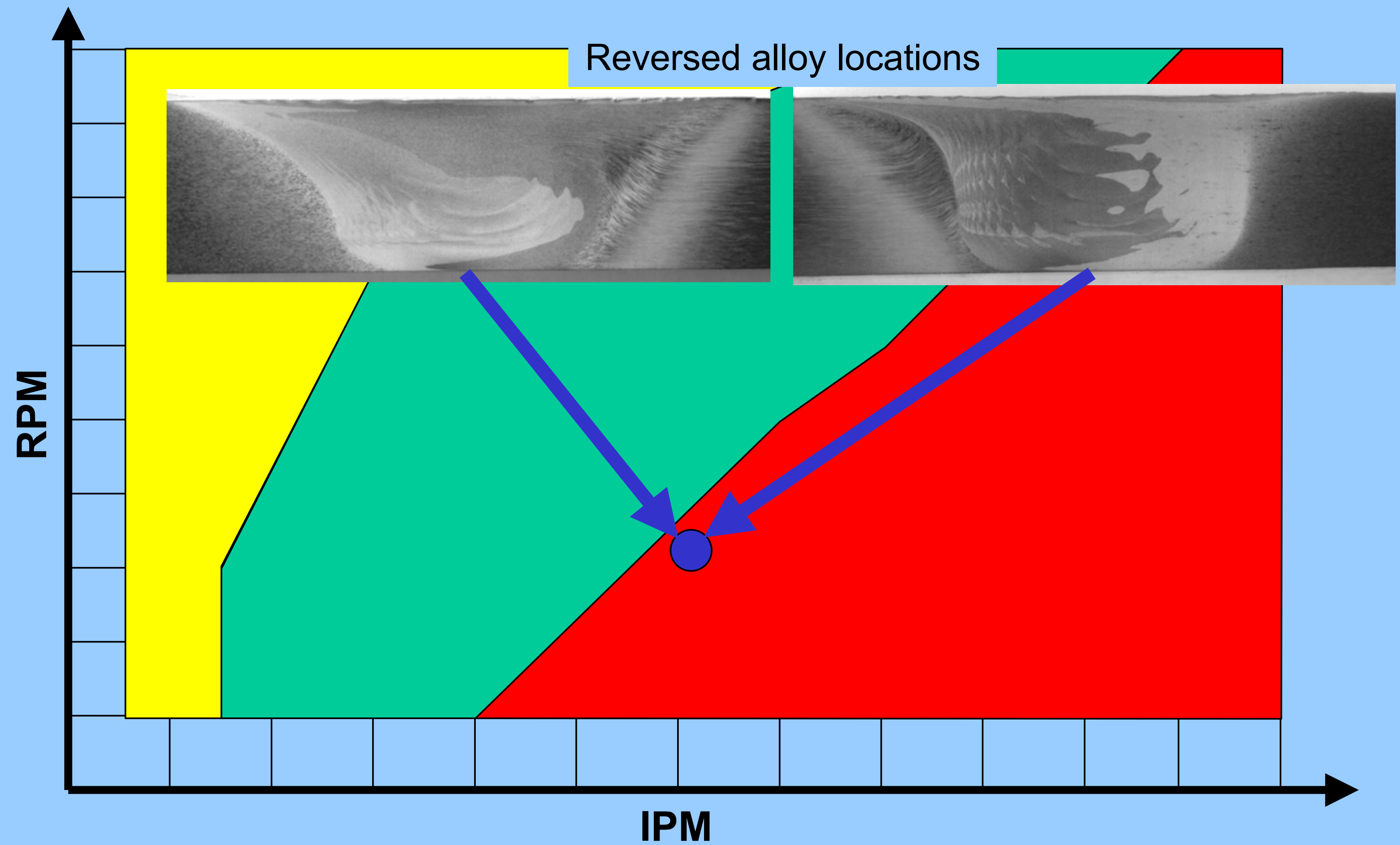
LOCKHEED MARTIN

- Thin gauge dissimilar alloy configuration
  - Root void and “worm hole”



Phase I Quick Look

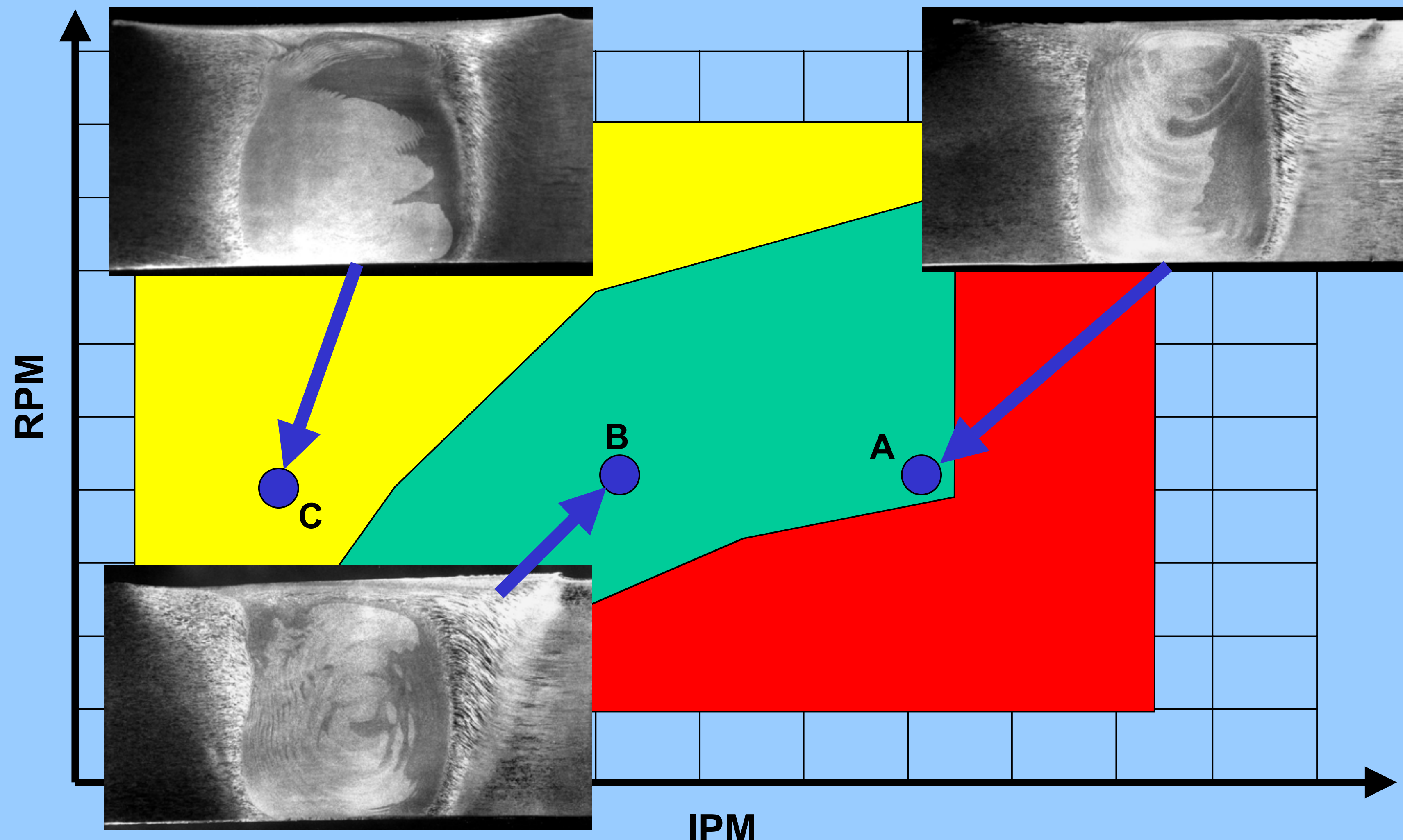
- Thin gauge dissimilar alloy configuration
  - Irregular nugget flow
  - Location of particular alloy influences flow within the nugget



Phase I Quick Look

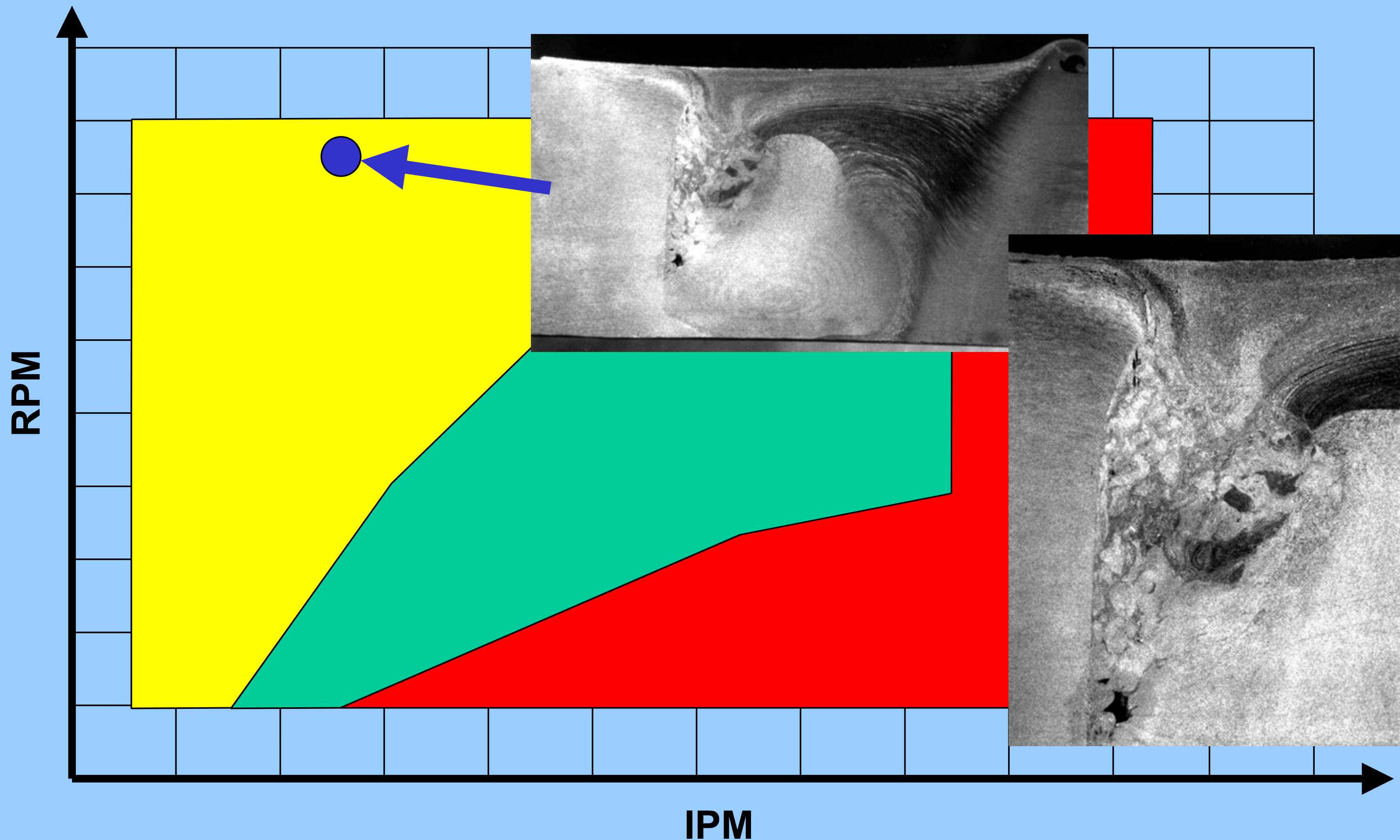
LOCKHEED MARTIN

- Thick gauge dissimilar alloy configuration
  - Low (A), medium (B), and high (C) heat input



Phase I Quick Look

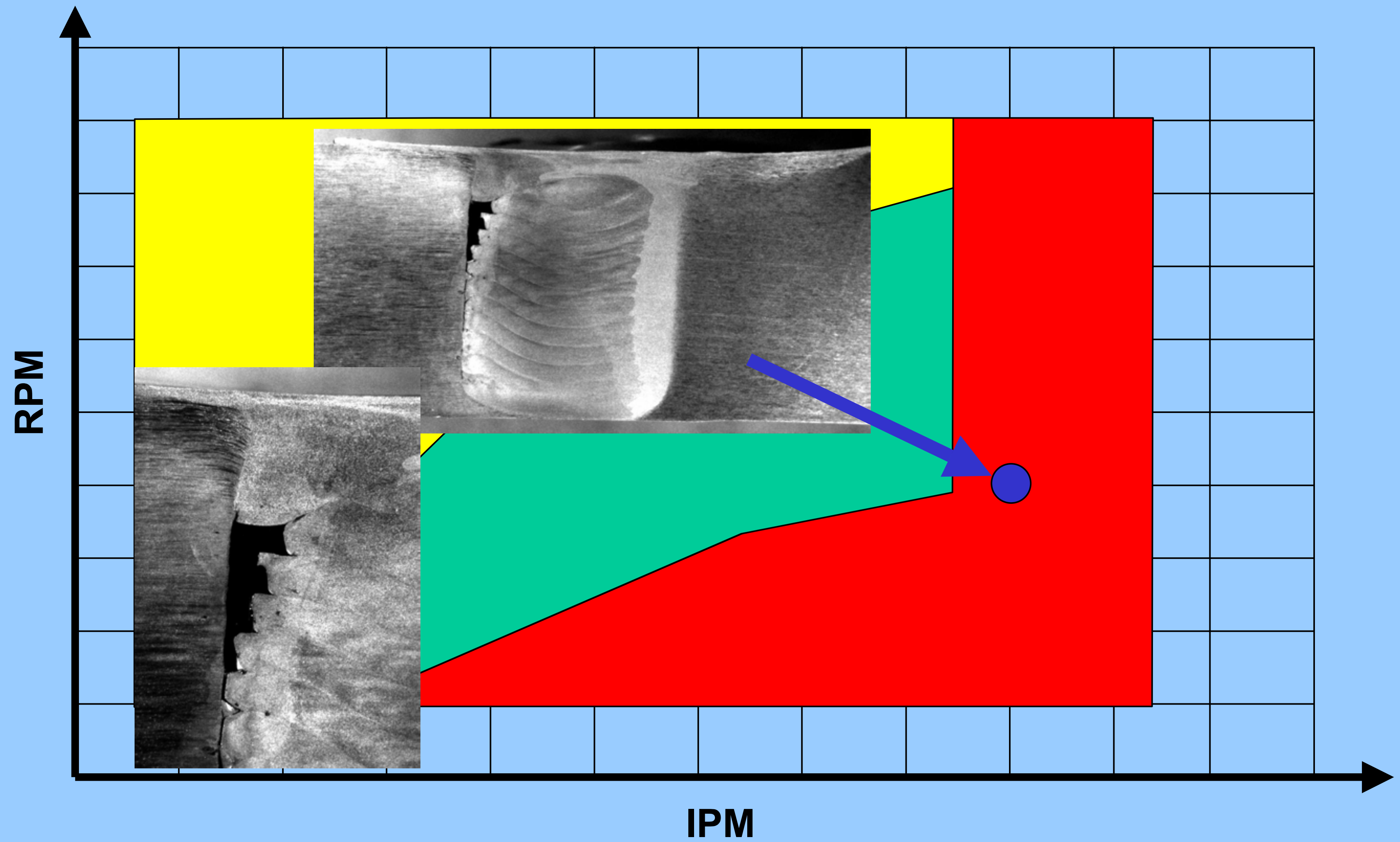
- Thick gauge dissimilar alloy configuration
  - High heat input weld/ collapse weld nugget with “worm holes”



Phase I Quick Look

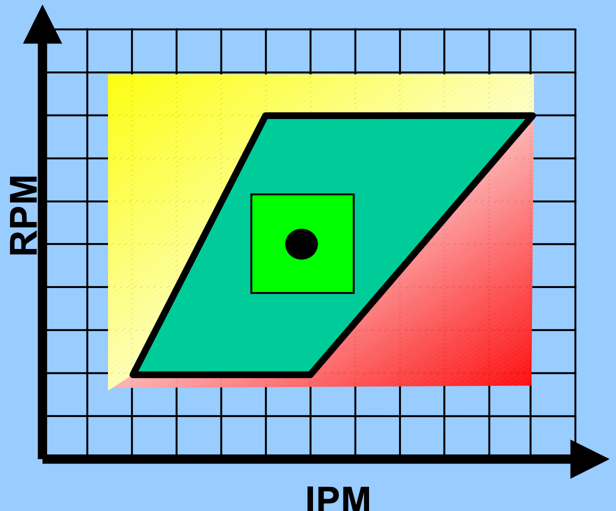
LOCKHEED MARTIN

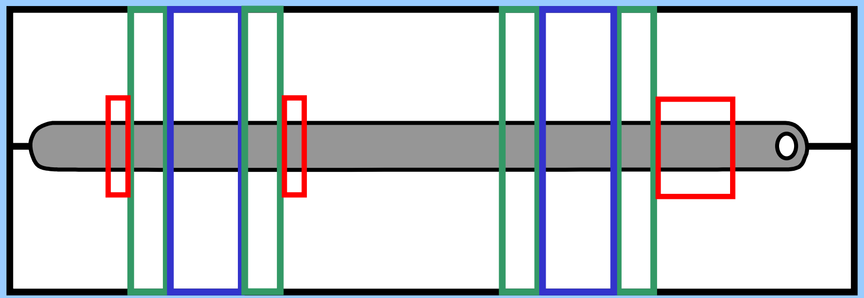
- Thick gauge dissimilar alloy configuration
  - **Low Heat Input Weld with "Worm Holes"**



Phase II Testing

- Weld schedules that provide acceptable metallographic profiles from Phase I are performed on 24" long test panels.
  - The longer weld provides adequate time for weld to reach stability
    - More reliable NDE response and tensile tests
  - Process load data becomes more consistent
- Tensile tests are conducted at the expected service temperatures of the weld
- These tests define the process envelope and begin to focus in on the "sweet spot"

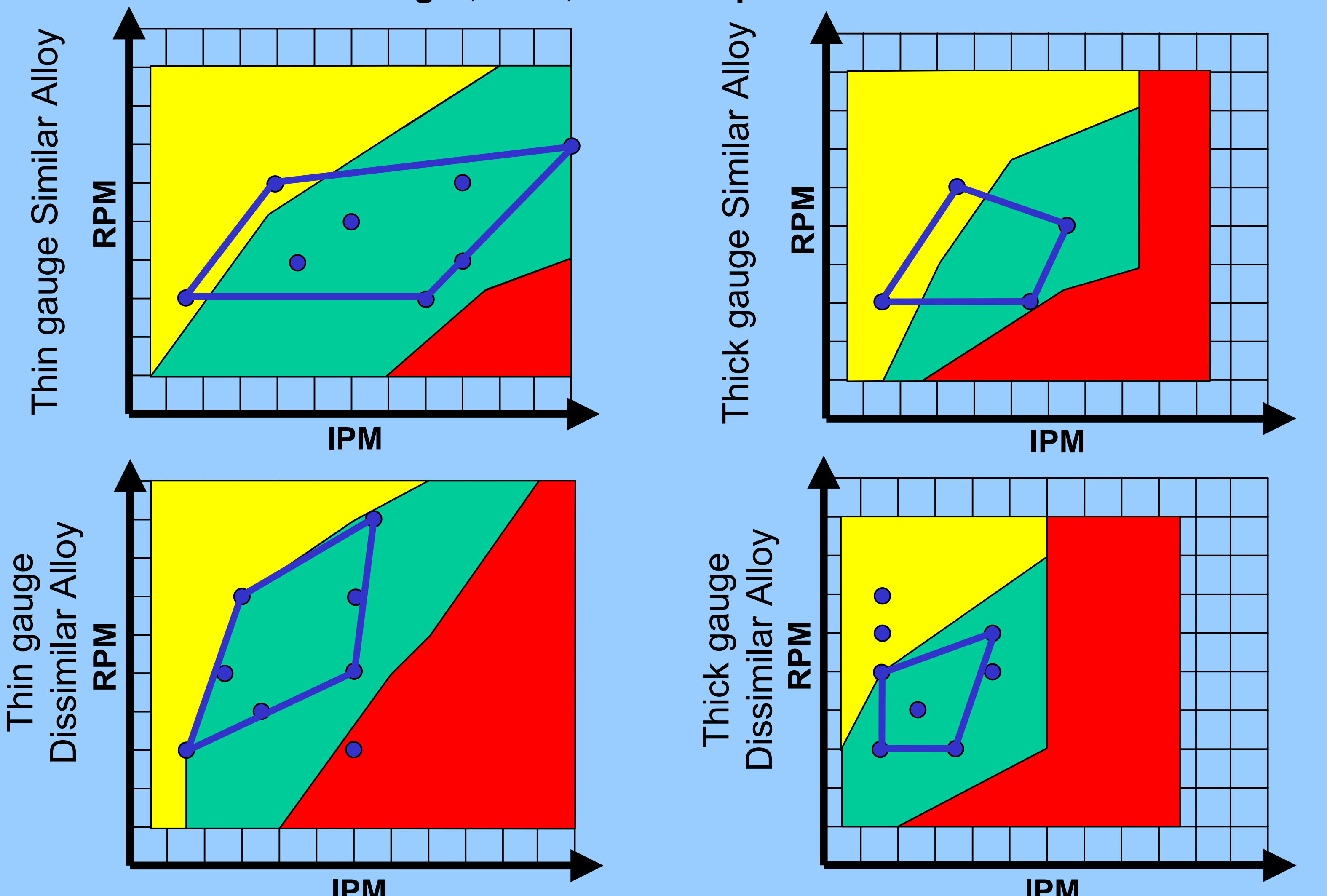




12"x24" Test Panel

Phase II Testing

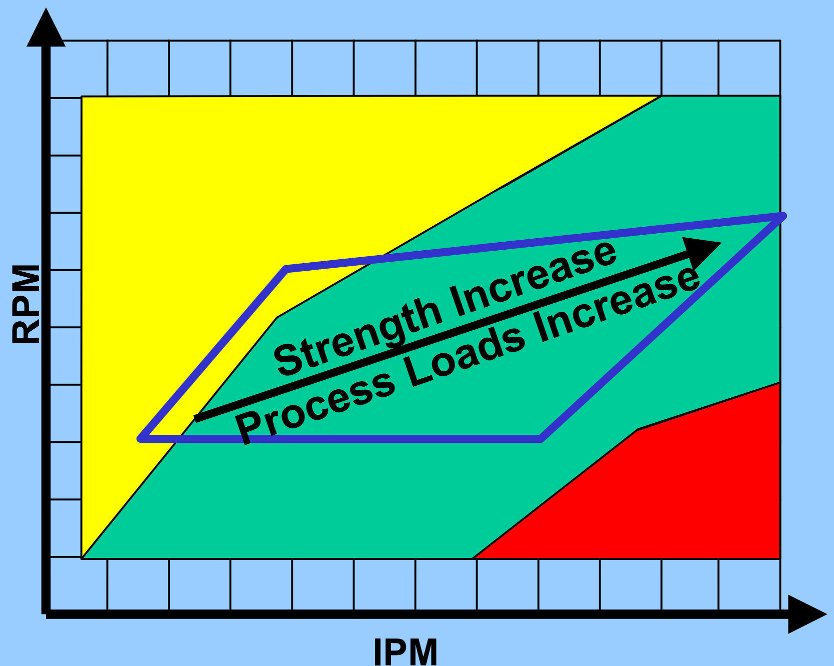
- The process envelope is delineated using the Phase II test data
  - **Mechanical strength, NDE, and tool performance are factors to consider**

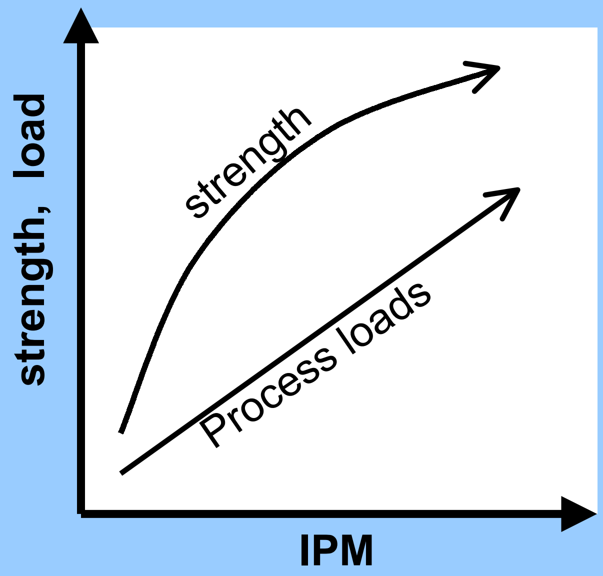


Phase II Testing

LOCKHEED MARTIN

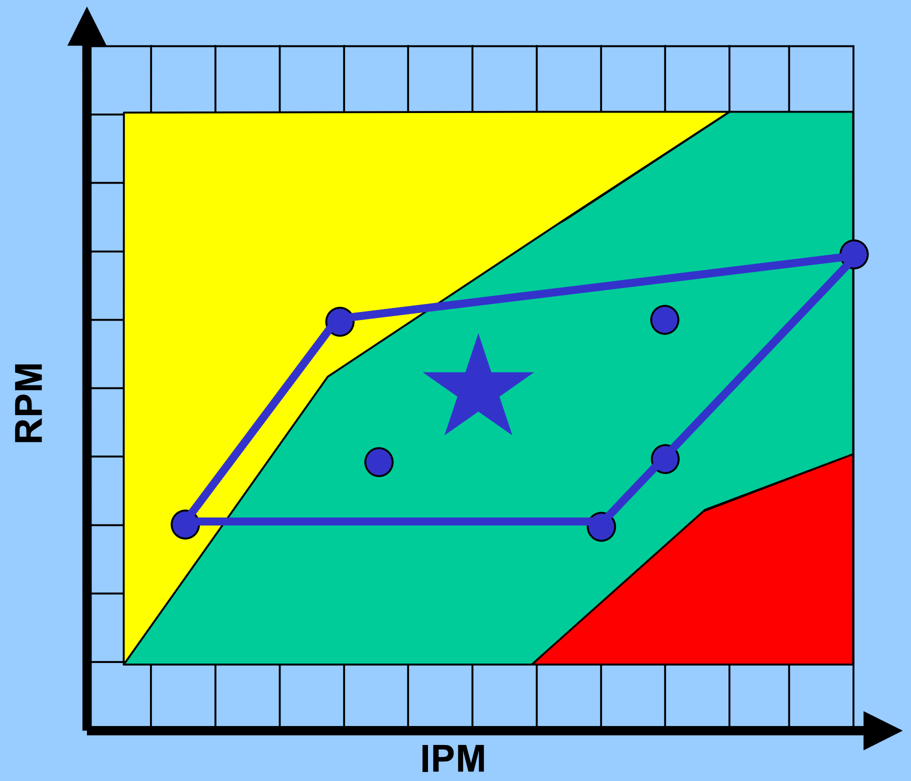
- Tensile strength increases with faster travel speeds
  - Cryogenic strength is more sensitive than room temperature strength to heat input
- Process loads, especially traverse loads, increase with travel speed
- The ability to perform cold welds depends on the machine's control system response





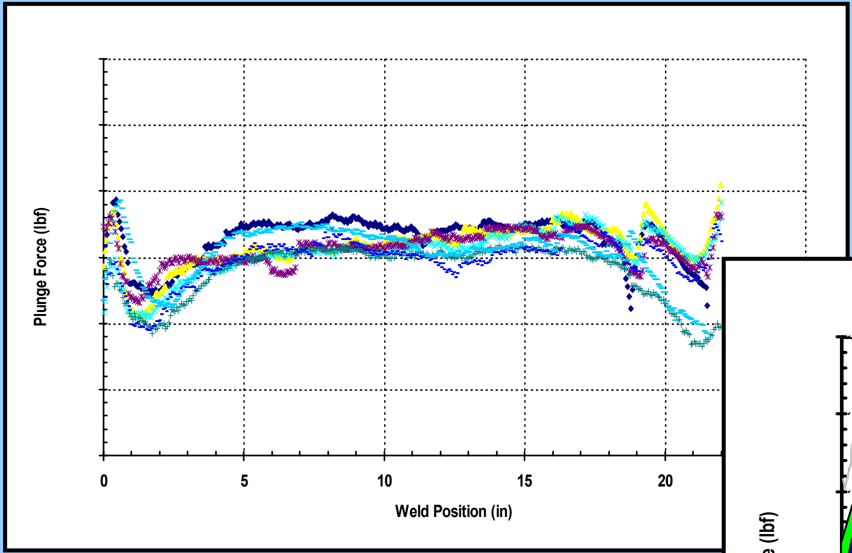
Weld Schedule Selection

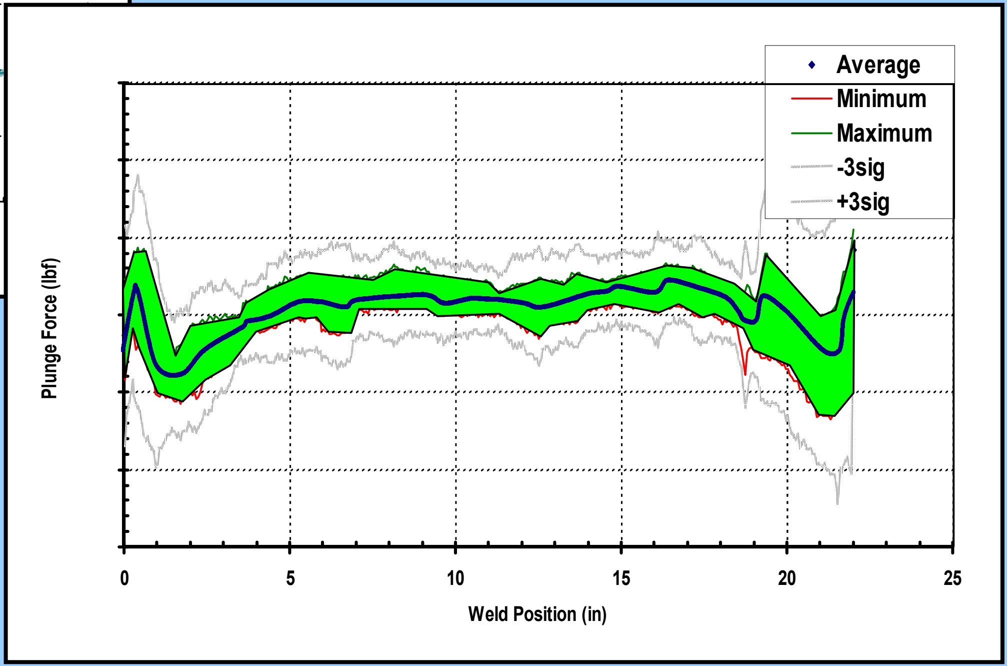
- Schedule selection is the best compromise between the following factors:
  - Process stability
  - Mechanical strength
  - NDE response
  - Machine capability
- The nominal schedule should be near the center of the process envelope to ensure robust performance to variations in the manufacturing environment



Process Characterization

- Multiple welds are performed with varied setup conditions
- Process information, such as plunge load, is collected and acceptable bounds are established





FSW Process Map Summary

LOCKHEED MARTIN

- The weld process performance for a given weld joint configuration and tool setup is summarized on a 2-D plot of RPM vs. IPM
- A process envelope is drawn within the map to identify the range of acceptable welds
- The sweet spot is selected as the nominal weld schedule
- The nominal weld schedule is characterized in the expected manufacturing environment
- The nominal weld schedule in conjunction with process control ensures a consistent and predictable weld performance