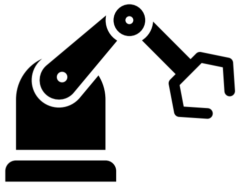
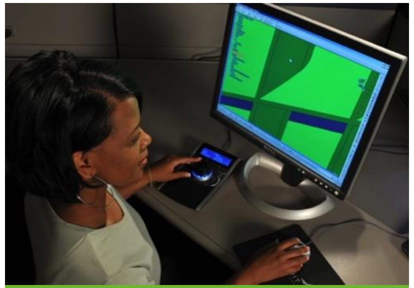
RESEARCH & TECHNOLOGY



Accuracy considerations for Robotic Systems in Aerospace Manufacturing

Spirit AeroSystems / Leading Global Aerostructures Tier 1 Supplier



DESIGN

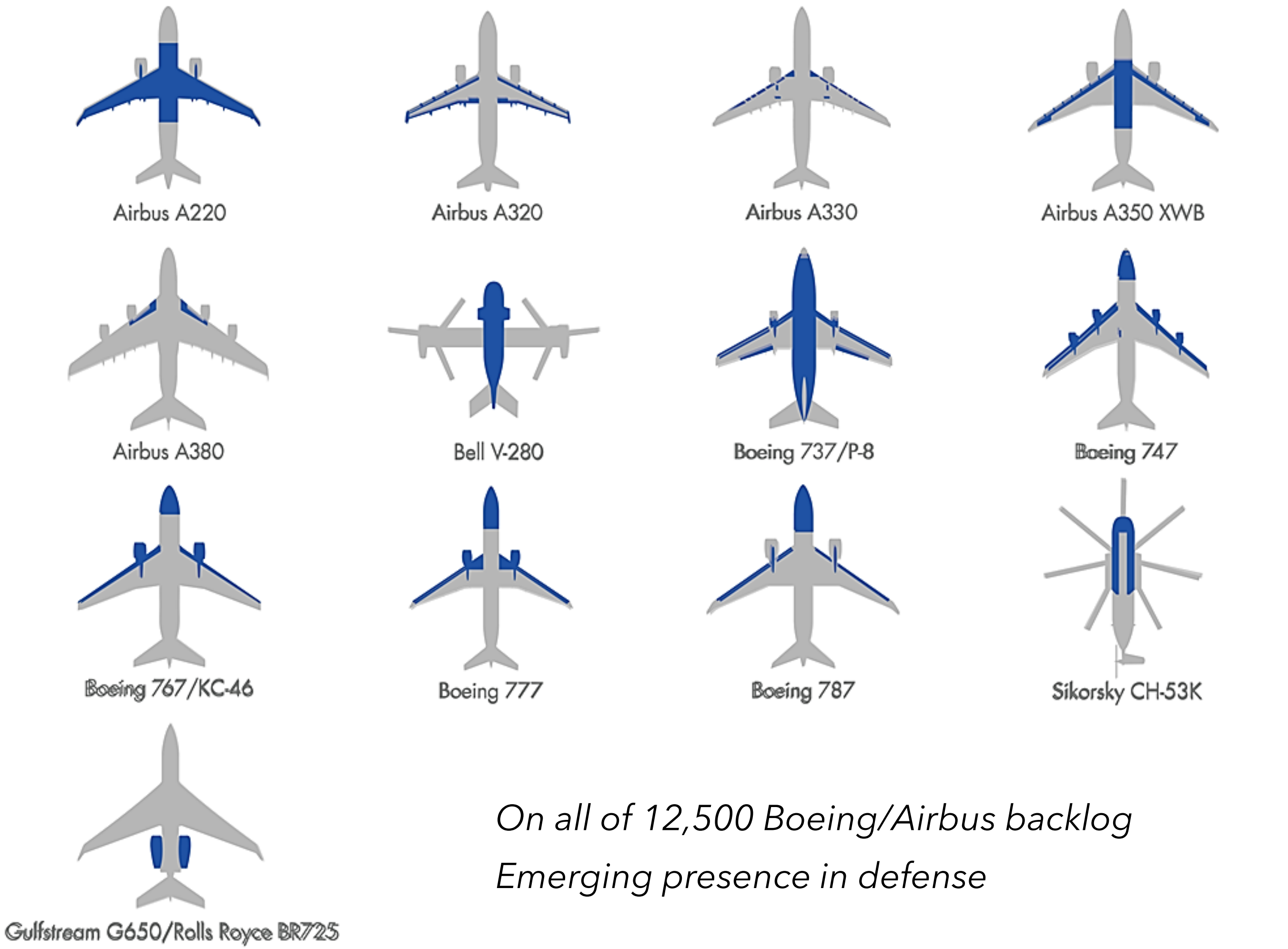
BUILD

SUSTAIN

FUSELAGE (52%)

PROPULSION (26%)

WING (21%)

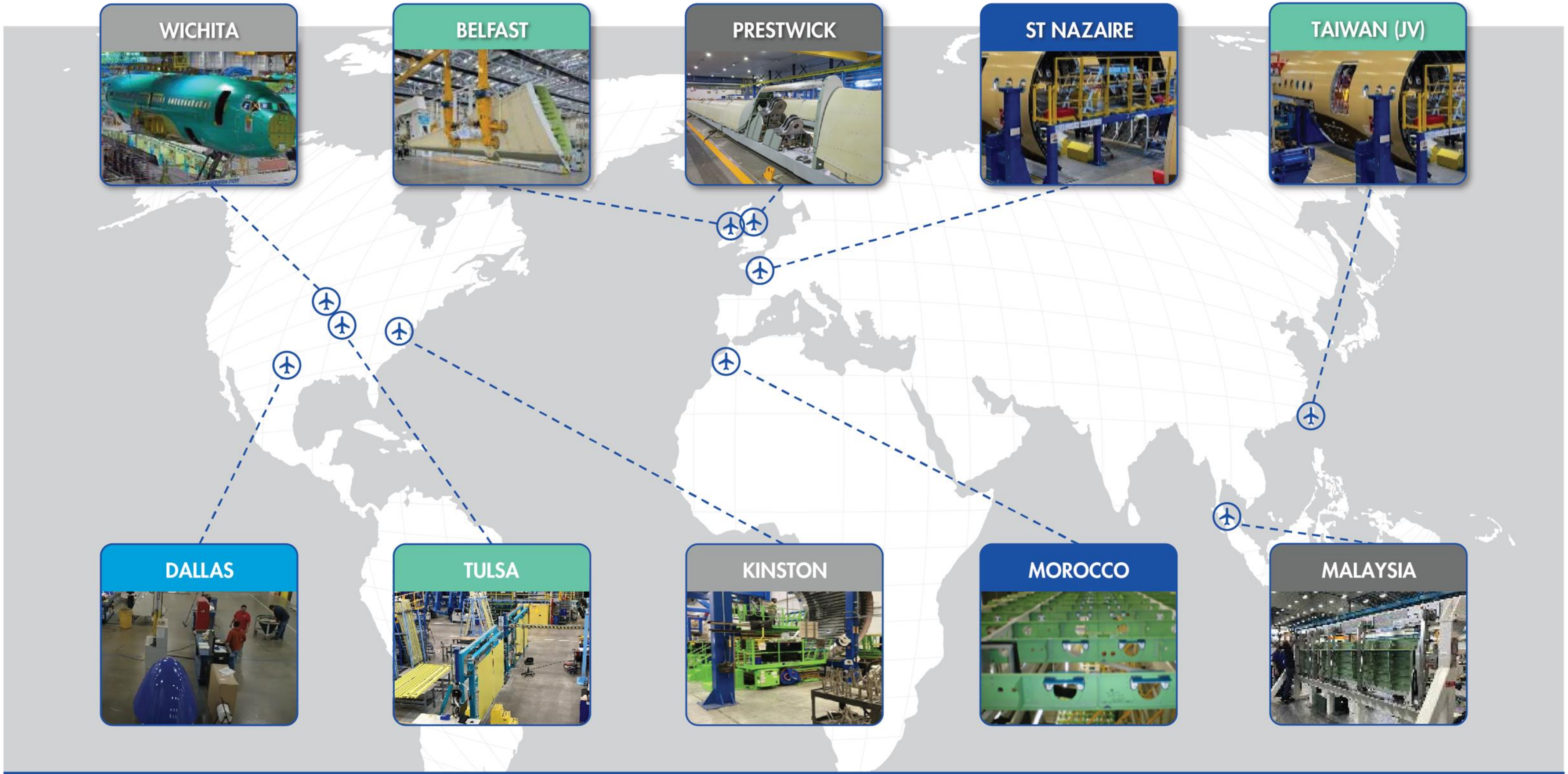


On all of 12,500 Boeing/Airbus backlog

Emerging presence in defense

SPIRIT AEROSYSTEMS

Global Footprint



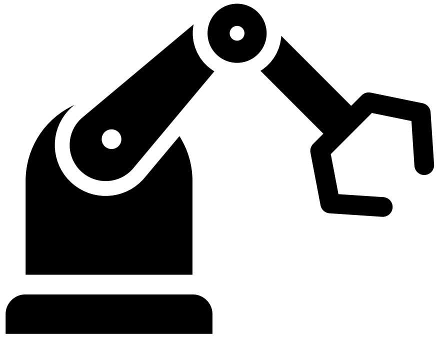
18,000+ commercial employees across 10 global locations

Background

- A lot of knowledge is learned throughout our internal developments. As such, a lot of understanding of robots and how they behave is available to those few who have spent time with these systems and applications. It is not a systematic process like traditional automation that is mature in this space.

- Curtis Richardson
  - is our automation Technical Fellow with a history in R&D of robotics and their accuracy. Well informed of current technology and challenges with robotic systems.

- Myself
  - 3 years experience measuring machine tools at Spirit.
  - 10+ Years in R&D for automation of aerospace processes
    - Personally involved in multiple robotic integrations from concept to shop floor.
    - Multiple years of R&D of robotics and their accuracies.
    - Provide advisement on general automation implementations including robotics.



Spirit's History with Automation

- Spirit has a long history of automation with traditional machine tools
  - CNC machining
  - Trim/Drill/Machining of large aerospace components
  - Carbon Fiber component automation
  - Automated Assembly of Aerostructures
  - Automated chemical processing/finishing
- Expectations from our history
  - High level of accuracy of small to large structures 40ft+
    - Many machines are specialized to achieve desired accuracy
  - Offline Programming in CAD environment
  - Machines that can produce a family of parts
  - Stable/predictable processes

Robotic Projects are Challenging

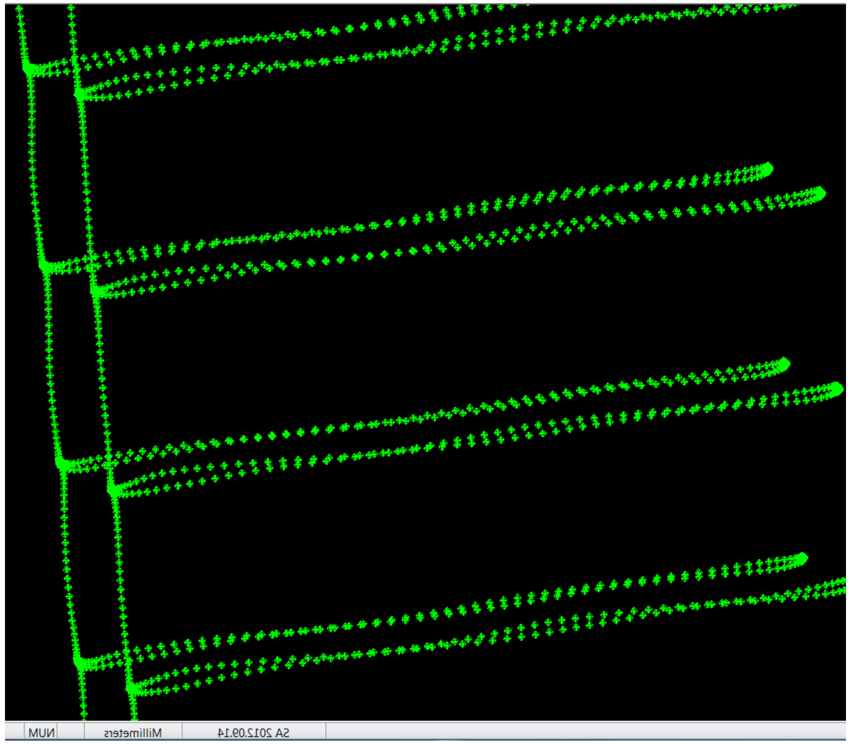
- Automation of aerospace processes is difficult
  - Many vendors have tried to apply automation from their experiences and often fail due to the strict requirements and processes.
  - Many of these failures are due to lack of robotic accuracy compounded with process difficulty .
- Choice of robot needs to be more than payload and reach, there is very little material to compare performance of a robot.
- Almost always require a rail axis or multiple robots.
- **<u>Understanding the risks associated with robotic accuracy is unknown when initially scoping a project.</u>**
- These risks and challenges will be found during integration phase and has failed or de-scoped many attempts in automation.

Robotic Accuracy R&D

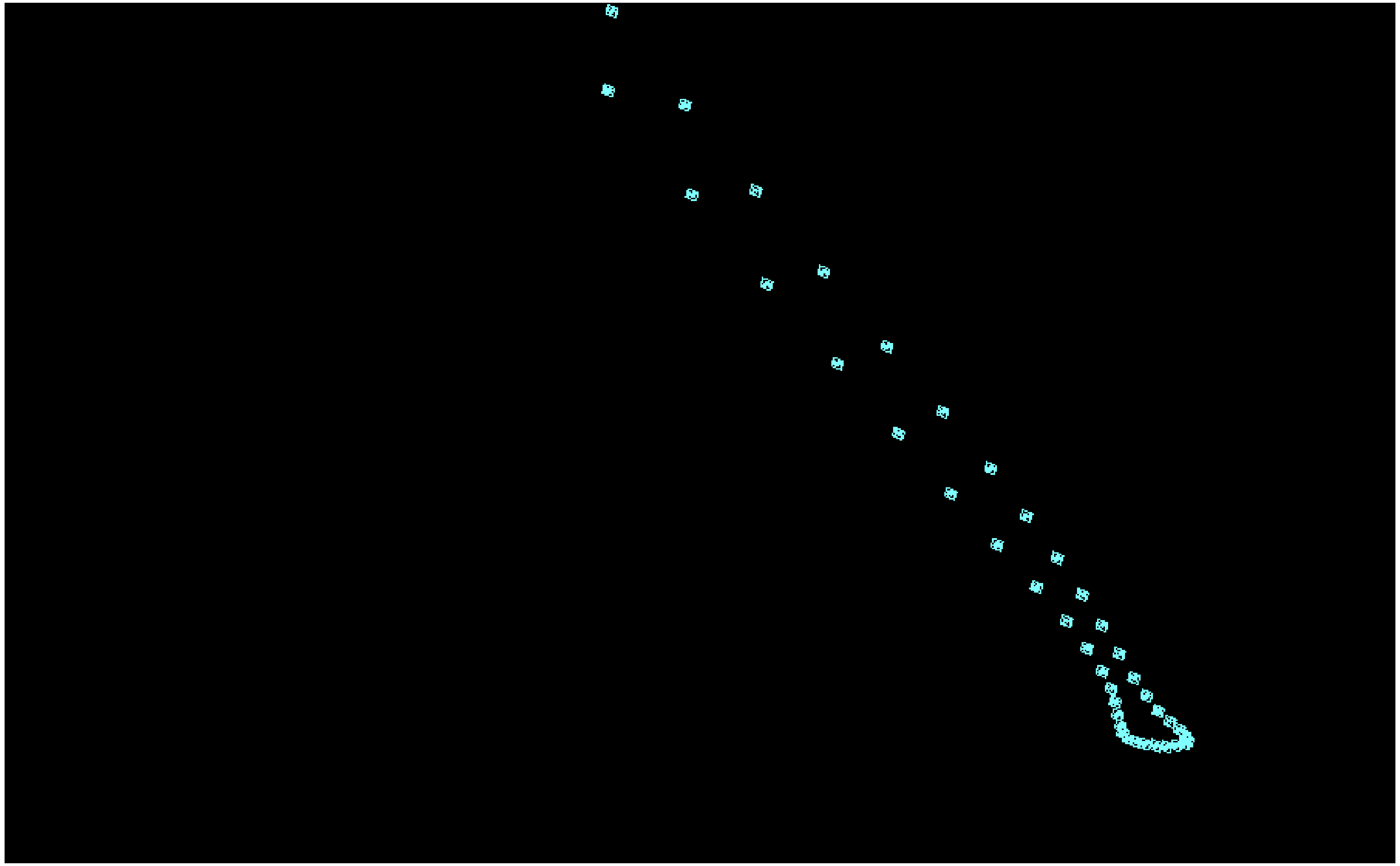
- Can normally achieve static accuracies that are good enough in the work envelope we expect.
- A rail axis is often required. Standard robotic rails are typically not good enough or advisable. Our best rail systems are typically custom built from the machine vendor.
- Integrated sensors for alignment can work well but often comes with a large cycle time cost.
- A custom calibration procedure is documented often using laser tracker methods.
- Defining TCP well is difficult to achieve ~.010 or less. With different recommendations how to achieve best TCP varies from manufacturer.
- Robot is not a good measurement system but is often requested.
- Rules of thumb is to not use max payload / reach, keep forces close to flange, and to keep reorientation at a minimum.

Robotic Perforation Development

- One of our most successful projects was nearly a failure.
- During the project we trialed multiple robots. he robot with the best static accuracy produced the worst quality. To the point it was a non-starter.
- 1+ years spent trying to get robots to drill small perforation holes using robotic motion. Tried everything that was available in the controller and physical manipulations. Never could get hole quality to acceptable limits.
- Next common step was to use quill end effectors to produce better quality holes. Industry wisdom that this would be slower and was partially correct.
- It became very clear the robot was the problem and was not stable during drilling. An end effector must take in account both the process and the robot.
- After that realization, our performance was up to 2 times faster than pure robotic drilling with near perfect quality.



Plunge Path

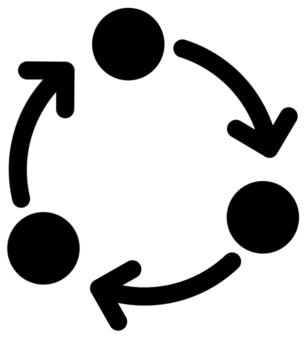


Current Focus / Challenges

- Dynamic accuracy is least understood.
- Most processes have external forces from drilling, clamping, end effector movement, and robotics motion that cause significant robotic deflection and damage to parts.
- Our installations with external rails often are custom rails with an intermediate controller. Makes it difficult to coordinate motion/calibration between the two controllers.
- Many attempts at using force sensors to provide insights into loads being applied. Robot controllers do not typically provide these types of inputs into the controllers.
- It is nearly impossible to predict behavior of robots in processes with prior usage. R&D time is critical on new applications.
- <u>Our most successful projects attempt to quantify these risks early and develop an end effector that alleviated this risks.</u>

Life Cycle Maintainability

- There is always a concern about the long-term robotic deployments and their ability to maintain accuracy on the shop floor. We have many typical machines that are 40+ years old, how does the robot fair after 10+? Will the robot be obsolete and replacement perform the same for the process?
- Laser tracker calibration and periodic checks are a must.
- Current maintenance workforce are accustomed to our machine tools. Where manual methods or linear lasers are the norm. Laser tracker use and decoding that data is difficult to convey. We try to automate these processes as much as possible.
- Many of our systems have a way to quickly check their condition before preforming work. In the case a robot is bumped etc.
- What is the long-term expectation of a robot's accuracy in a work envelope. What role does temperature play in their accuracies. Would a replacement robot perform the same?



Research & Technology

Spirit AeroSystems

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