Model Preparation, Operations, and Access

Presentation to
AVT-328 Technical Course
Impact and Advanced Implementation of Cryogenics in Aerodynamic Testing

Scott GOODLIFF, USA

Agenda

- **Model Preparations**
  - Pre-Assembly
  - Model Assembly
  - Instrumentation Integration
  - Surface Preparation
  - Pre-Test Model System Checks
- **Operations**
  - Tunnel Conditioning
  - Testing / Data Acquisition
  - Test Matrix Sequencing
  - Test Envelopes
- **Model Access**
  - Cryogenic Model Access Background
  - Facility Processes

Model Preparations

Pre-Assembly

- Importance of pre-test model preparation is amplified for cryogenic models
  - Complexity of models, test environment, and integration of instrumentation make it difficult and time consuming to correct a problem later

Better preparation = better chance of successful test!

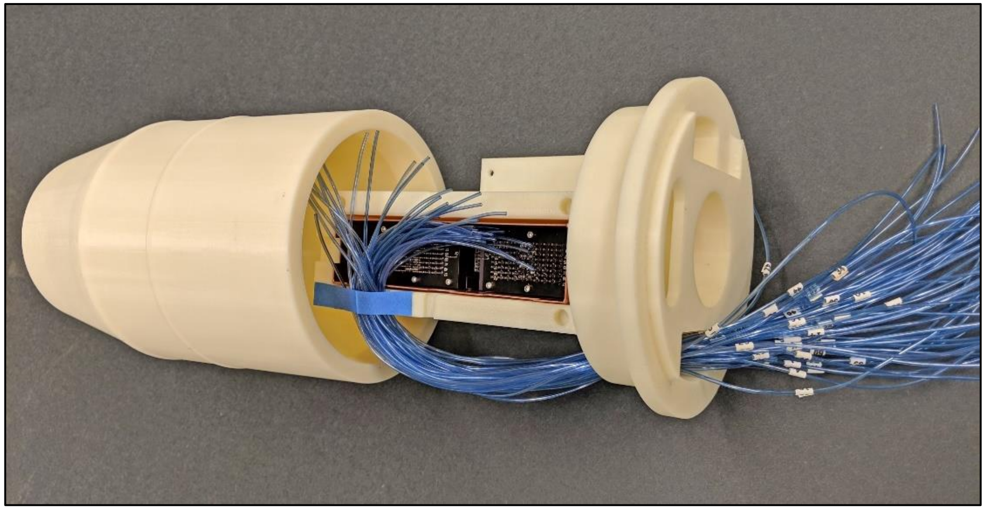
- **Typical Pre-Test Tasks**
  - Clean Model Hardware
    - cryogenic testing require models to be fabricated from special alloys that can easily rust
    - models pulled from storage need to be cleaned of oils or other hydrophobic agents prior to assembly
  - Purge Model Pressure Tubing
    - dry air or nitrogen purge on internal pressure tubing to eliminate moisture contamination
    - any moisture in the tubes could freeze and compromise pressure measurements during the test

Pre-Assembly, Continued

✈ Typical Pre-Test Tasks

- Clean all Fastener Holes
  - clean threaded holes and pin holes, tape over them to prevent contamination prior to assembly, saves time and mitigates assembly problems

- Rapid Prototyping
  - 3-D printed parts and model components can be extremely beneficial for verifying fit of internal instrumentation, fit of cables and tubing, and identifying assembly sequences



Model Preparations

Pre-Assembly, Continued

✈ Typical Pre-Test Tasks

- Model Fasteners
  - cryogenic models require specialty fasteners that can take time to procure and/or fabricate, possible long-lead items (certs required for fasteners used in critically stressed areas)
  - most common fastener material for cryogenic applications is A286
  - high-strength steel alloy (Unbrako or equivalent) can be used down to -50^{o}F or 225K
  - common pin material is Nitronic 60/40, or VascoMax if more strength is needed

- Cryogenic Testing of Components
  - model components can be tested cryogenically to identify any thermal issues before the model is assembled

Need photo of component cryo test

Model Assembly

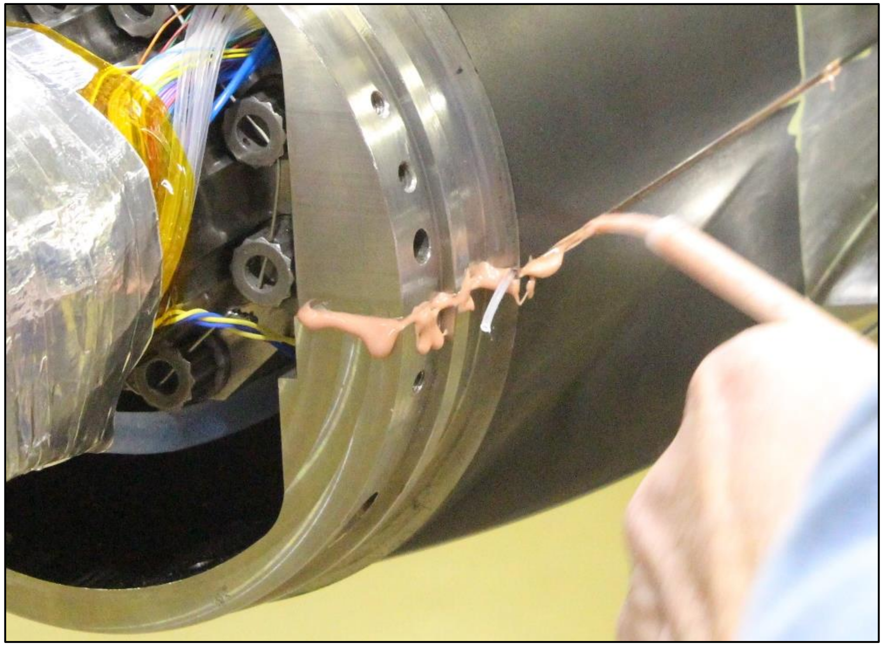
- Assembly of cryogenic models for high Reynolds numbers requires special attention in several areas
- Model assembly typically completed outside of the test section
  - Minimizes moisture from personnel presence
  - Assembly issues, troubleshooting, and instrumentation checkouts can be more effectively worked outside of the tunnel

- **Model Assembly Focal Points**
  - Fastener Retention
    - in most cases, 2 forms of retention are required for each fastener
    - acceptable forms of retention for cryogenic applications
      - → torque
      - → Loctite threadlocker
      - → safety wire
      - → secondary retention fastener (dowel pins or pull-pins)

Model Assembly, Continued

✈ Model Assembly Focal Points

- Sealing of Model Joints
  - thermal contraction effects can create unwanted gaps in model joints
  - flow through gaps that are not a part of the design can compromise vehicle aerodynamics
  - sealer is typically applied between all model joints
    - → Examix
    - → Xantopren
    - → RTV
  - consideration must be given to effect of sealant on fit and finish of joints
    - → Does the sealant create a gap or step in joints that would be more detrimental than flow?
    - → Model design provision for sealant (i.e. trench, relief, etc.)?



Model Preparations

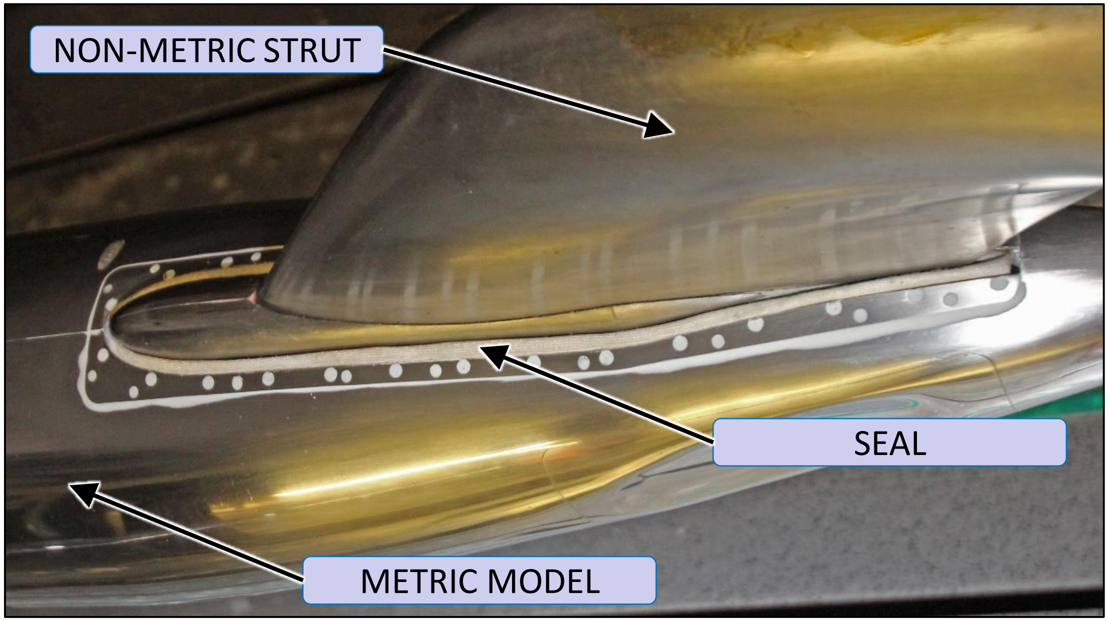
Model Assembly, Continued

Model Assembly Focal Points

- Metric-to-Non-Metric Seals
  - flow blockers sometimes required for metric-to-non-metric boundaries
  - seals must remain flexible at cryogenic temperatures (fiberglass is common)
  - *fabrication and fit of these seals is a black art*

→ seal must make contact with opposing surface in order to seal, but must not affect balance measurements

→ full model cryo cycle used to check seal effects at test temperature



Model Preparations

Model Assembly, Continued

Model Assembly Focal Points

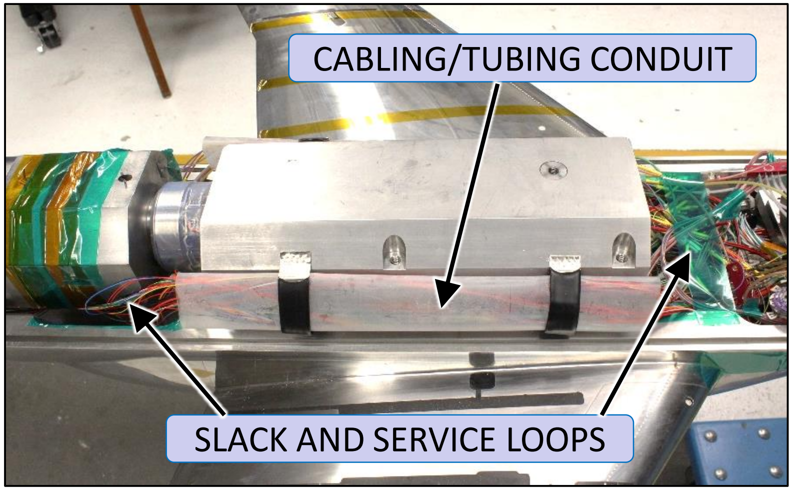
- Bolt Hole Preparation
  - bolt hole filler retention is critical
  - filler changes or departure can affect results at high Reynolds number
  - bolt/pin hole countersinks and counterbores can be scuffed up to provide filler material with better adhesion
  - sometimes there simply isn't enough depth to the hole, consider changing filler material or scuffing up the bolt head

Instrumentation Integration

- Models are typically large enough to host an array of sensors, transducers, and other measurement devices
- Special considerations given to internal instrumentation which may also be exposed to cryogenic temperatures
  - Applies to thermally sensitive measurement devices as well as cabling/tubing

Instrumentation Focal Points

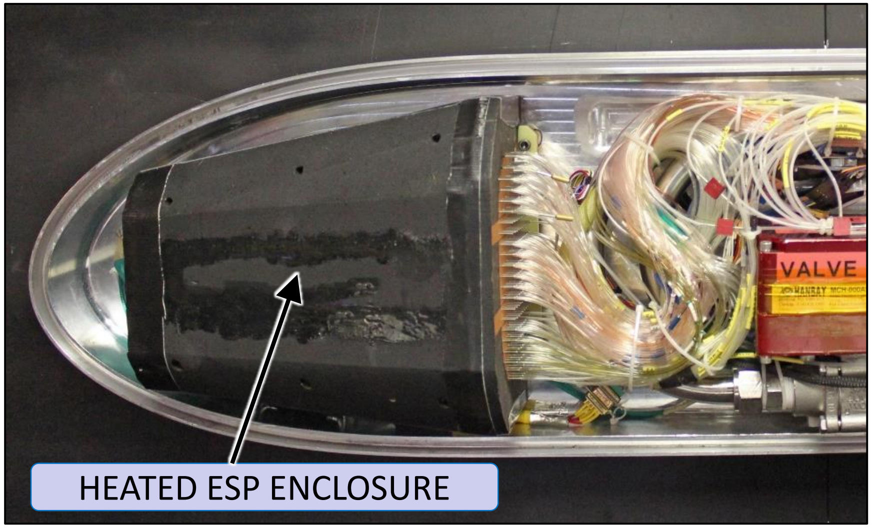
- Cabling/Tubing Considerations
  - slack and "service loops" should be provided to compensate for thermal contraction
  - tie-downs and metric points of attachment should allow cabling/tubing to slide freely (zip ties, shrink tubing, etc.)
  - *special emphasis on metric-to-non-metric boundaries, critical for high-quality force/moment measurements*



Instrumentation Integration, Continued

✈ Instrumentation Focal Points, Continued

- Instrumentation Thermal Considerations
  - develop thermal strategy for instrumentation
    - → calibrate device(s) at various temperatures to compensate for it
    - → keep device(s) at constant temperature
      - installation of insulated heated enclosure(s) to keep device(s) at constant temperature



Force/Moment Balance Thermal Conditioning

- balance heating/cooling line installed for expediting balance thermal conditioning
  - dry nitrogen gas is used in a warm or cold state
- dry nitrogen purge used on balance to keep moisture/condensation away from strain gauges during model accesses

Surface Preparation

- State of model flow surfaces critical for high Reynolds number testing
- Thin boundary layer makes small protuberances on model detectable in force and pressure data
  - Many techniques and processes used to prepare a model surface for high Reynolds number testing

- **Key Surface Preparation Techniques and Processes**
  - Surface Roughness
    - typical model surface roughness after fabrication of <64 μin or <1.6 microns Ra
    - roughness measurements made with profilometer before and after the test to document the state of key model surfaces and ensure model meets requirements

Need photo of profilometer in use from ETW

Surface Preparation, Continued

✈ Key Surface Preparation Techniques and Processes, Continued

- Model Filler
  - many different types for different applications

→ Evercoat
primary filler material for bolt holes and other model filler requirements (polyester glazing putty)

→ UV filler
combination of quartz powder and Loctite, requires UV light to cure, slightly better performance and adhering capability than Evercoat but much harder to work with

→ Two-part RTV
used in filler and sealing applications requiring a more flexible solution, two-part used in the tunnel due to the dry conditions

→ Epoxy
used for permanent filling applications, 9309 epoxy + carbonspheres or 9394 epoxy used successfully

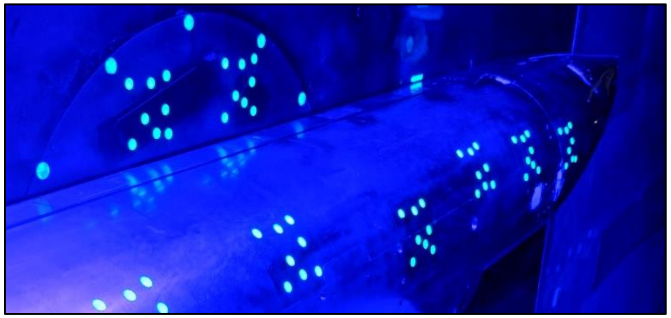
Need photo of ETW model filler example

Surface Preparation, Continued

Key Surface Preparation Techniques and Processes, Continued

- Paint Application
  - temperature sensitive paint (TSP), pressure sensitive paint (PSP), and other paint applications supporting flow visualization
  - paint typically applied outside of the tunnel to prevent tunnel contamination and enhance curing
  - critical to properly prime the model to maximize adhesion of subsequent paint layers

- Model Deformation Targets
  - Facility dependent method for application
    - → Flourescent marker
    - → Thin self-adhesive transfer targets



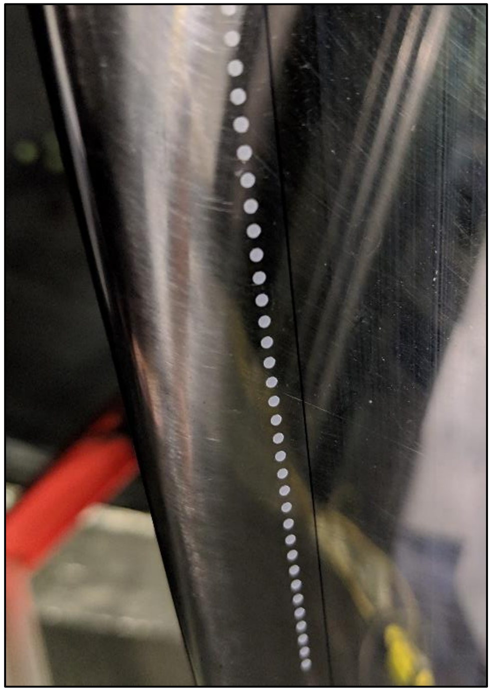
Need photo of ETW targeted model

Model Preparations

Surface Preparation, Continued

✈ Key Surface Preparation Techniques and Processes, Continued

- Fixed Boundary Layer Transition
  - many methods of application approved for cryogenic use
  - in all cases, especially self-adhesive dots, proper cleaning of the metal surface is critical for maximum adhesion



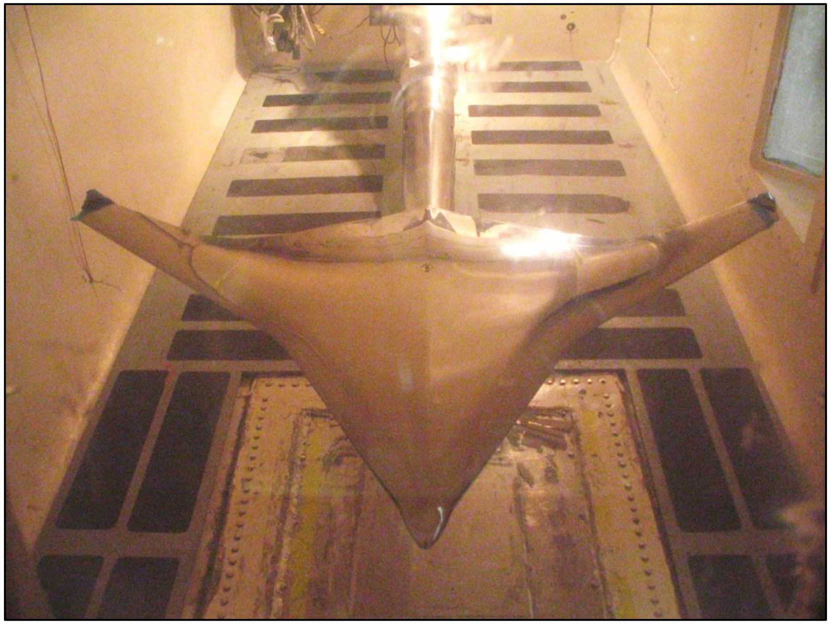
→ self-adhesive dots
- most commonly used type of fixed transition
- available in many heights
- typically vinyl, but heights less than 0.002 inches or 0.05 mm may be foil

→ epoxy
- epoxy dots more durable than self-adhesive, but more labor intensive for application, requires shaving to proper height

→ grit
- carborundum grit used for less-precise applications in which the drag increment of the grit itself is less critical (fuselage components)

Pre-Test Model System Checks

- Model integrated system check completed at cryogenic test temperatures outside of the tunnel
- Used to validate thermal conditioning of all instrumentation, verify/characterize proper balance response throughout test temperature range, and ensure balance signals are free from fouling contamination

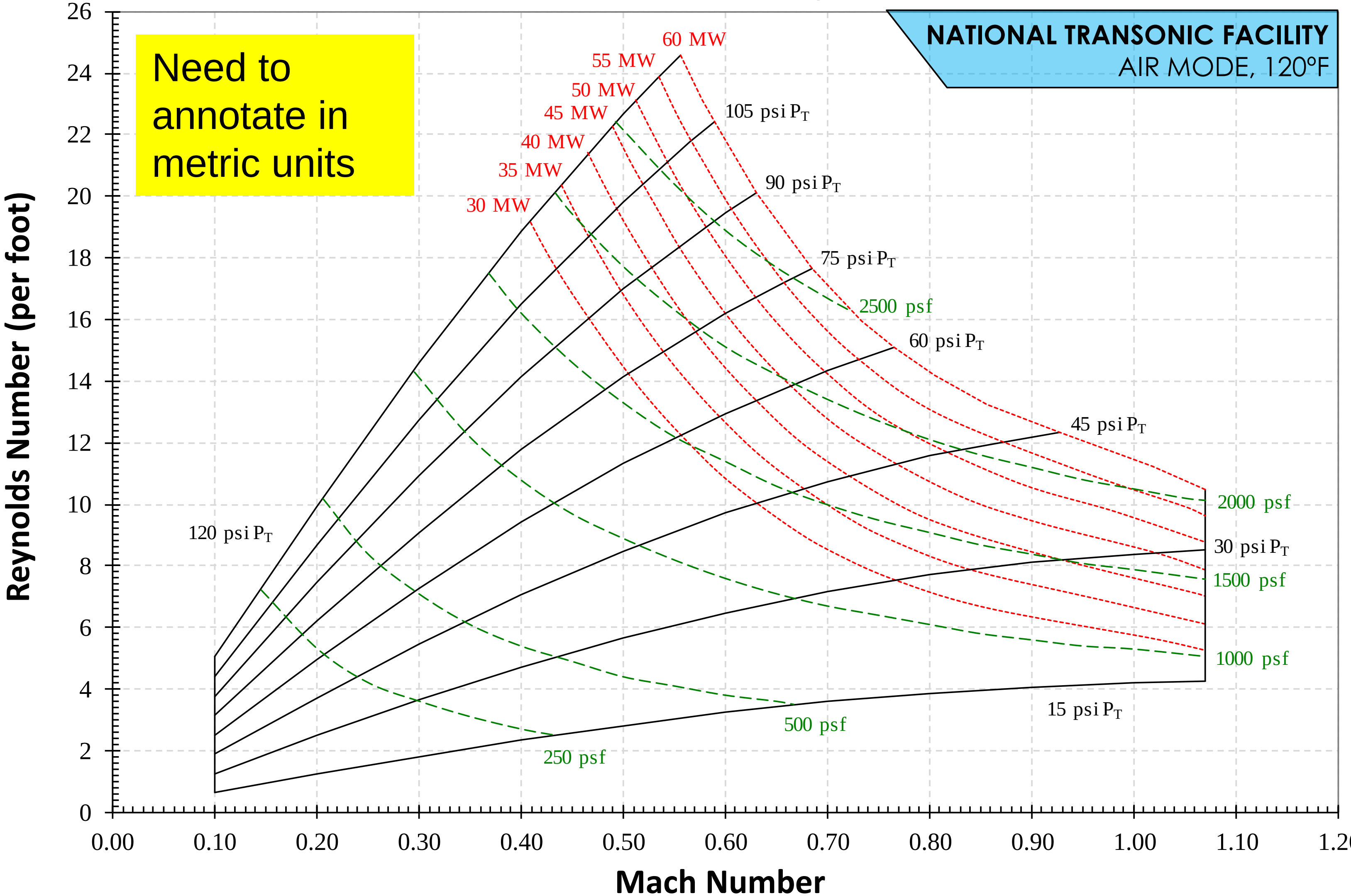


Operations

Need ops photos from European facilities

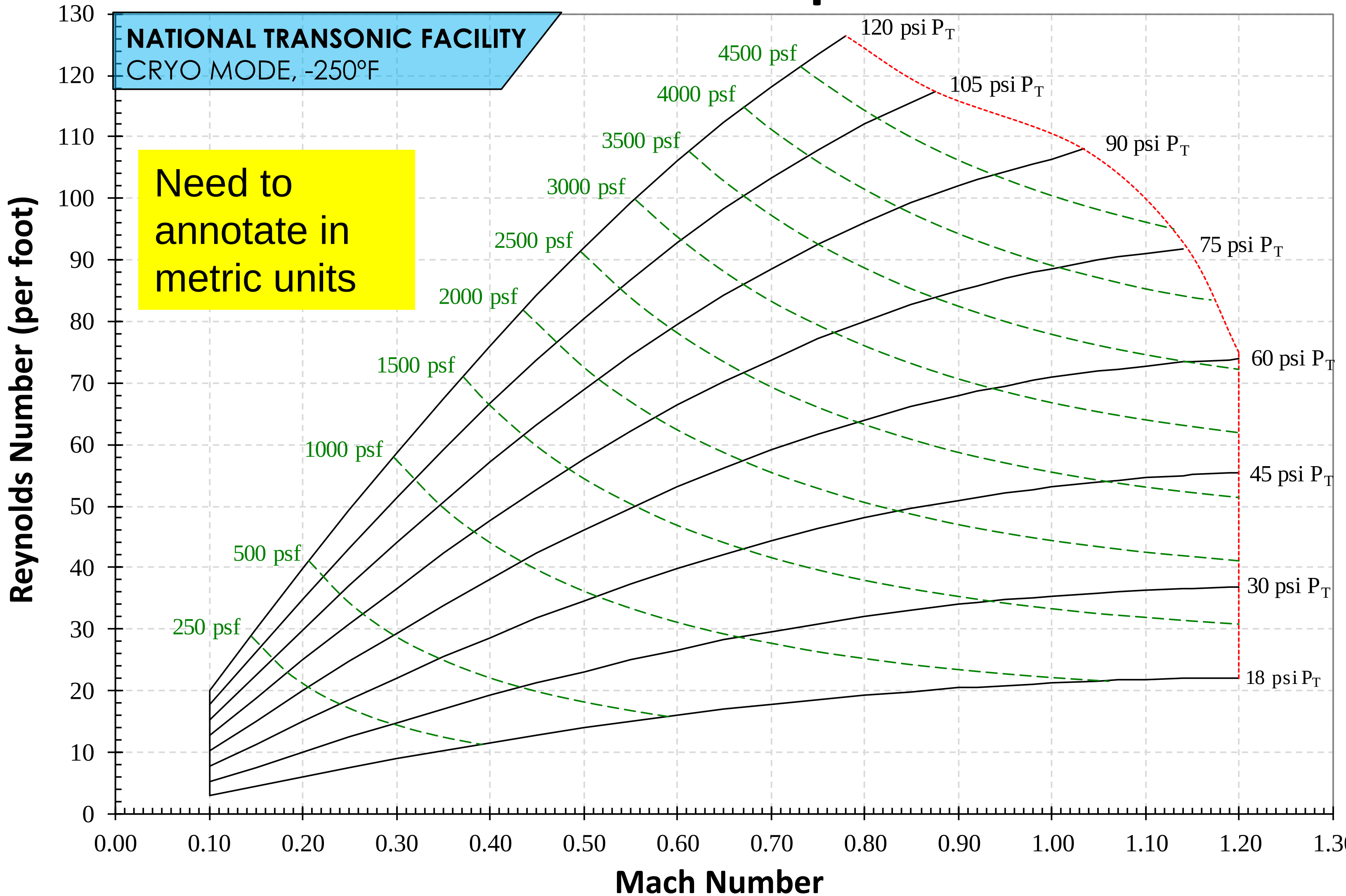
Test Envelopes

Need to annotate in metric units



Operations

Test Envelopes



Operations

Test Envelopes

Need envelopes from European facilities

Tunnel Conditioning

- Tunnel internal environment and thermal state must be properly conditioned prior to data acquisition
- Processes for conditioning the tunnel similar for all facilities in cryogenic mode
  - Some processes not applicable to tunnels capable of testing in air mode
- **Key Processes for Tunnel Conditioning**
  - Gas Exchange
    - not applicable for testing in air mode
    - all air must be purged from tunnel circuit and replaced with nitrogen gas
    - typically completed at near-ambient conditions (100°F or 310K)
    - process also used to eliminate any residual moisture in the tunnel
    - entire process takes several hours to complete
    - process reversed to go from nitrogen mode to air mode testing (NTF only)

Tunnel Conditioning

✈ Key Processes for Tunnel Conditioning, Continued

- Cooldowns
  - liquid nitrogen injected into tunnel circuit to cool the freestream down to desired test temperature
  - completed at very low speed (~Mach 0.1) to minimize nitrogen consumption
  - typical cooldown rate of 1.2°F or 0.7K per minute *(verify rate at ETW)*
  - can take many hours to cool down to -250°F or 116K

- Warmups
  - fan heat used to warm up tunnel (no nitrogen injection needed)
  - rate of warmup same as cooldown rate

- Model/Structure Conditioning
  - model and tunnel internal structure thermally conditioned to near freestream temperature
  - critical for stabilizing freestream flow and obtaining high-quality data
  - model, tunnel, and instrumentation temperatures constantly monitored for stability criteria
  - model reaches conditioned temperature before tunnel structure
  - can take several additional hours

Testing / Data Acquisition

- Wind-on cost of cryogenic testing is elevated due to high power and liquid nitrogen cost
- Processes for acquisition focused on quality and efficiency to reduce consumables

- **Key Tenets of Cryogenic Testing and Acquisition**
  - Wind-Off Zeroes
    - very important for high-quality force/moment data
    - frequency of wind-off zeroes dictated by thermal stability of balance and other instrumentation (can be configuration/condition dependent)
    - standard practice of acquiring zero data very close to thermal state of wind-on data
  - Acquisition Duration
    - use of continuous sweep and active conditional sampling
    - optimized point-to-point model movement to reduce time on point
    - sharpened focus during wind-on testing, emphasis on reduced distractions and discussions while on condition

Shorter Acquisition Times = Lower Nitrogen Usage = Lower Test Cost

[Integrate unique European facility acquisition procedures]

Testing / Data Acquisition, Continued

✈ Key Tenets of Cryogenic Testing and Acquisition, Continued

- Thermal Stability of Test Section
  - temperature sensors located in the test section and other tunnel areas monitored to ensure freestream flow is thermally stable and uniform
  - may require additional settling time prior to acquisition

- Review of Test Data
  - due to focused nature of acquisition, test data computed after a run set is completed
  - must be reviewed by test engineer or other representative prior to delivery to the customer, ensure corrections and data are computed correctly

[Integrate unique European facility acquisition procedures]

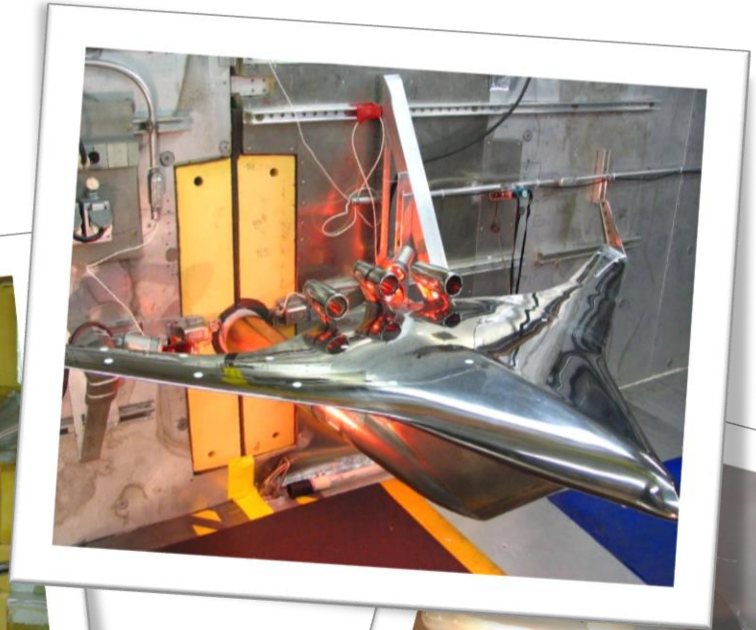
Test Matrix Sequencing

- Longer duration of some cryogenic processes emphasizes proper sequence of test matrix elements

- **Efficiency Guidelines for Test Matrix Sequencing**
  - Process-Oriented Changes
    - typical order of most efficient to least efficient process changes
      - → Mach number
      - → pressure changes at constant temperature
      - → temperature changes
    - most temperature/pressure changes should be done at lower Mach number to minimize nitrogen consumption
  - Model Configuration Changes
    - model changes at deep cryogenic temperatures require longer warming and conditioning times
    - if possible, model changes should be staged at warmer temperatures
      - → many times this is not possible, but expectations should be set accordingly for repeated cryogenic model changes

[Validate statements with European standard practice]

Model Access



Unique Nature of Cryogenic Model Access

Typical Wind Tunnels	Cryogenic Wind Tunnels
Easy ingress/egress Optimized for efficiency/production	More complex ingress/egress Optimized for moisture reduction

Key Takeaways for Cryogenic Model Accesses

- Process to make the model accessible takes additional time due to complexity of facilities and safety (nitrogen)
  - different facility designs yield different access procedures and methods
- Model must be warmed up from cryogenic temperatures prior to work being completed
- Emphasis on moisture reduction
  - limit personnel presence around model
  - constant dry air purge around model
  - limit time required to complete a change

Model Access Procedures, ETW

- Include abbreviated outline of ETW model access process

- Include sketches and/or sequential photos of process

[Requires discussion with ETW]

Model Access Procedures, NTF

- Ingress Process
  - secure nitrogen injection system
  - open tunnel and insert access housings
  - warm model and condition environment for personnel

- Egress Process
  - purge access housings of all moisture
  - retract access housings and close tunnel
  - re-condition tunnel for testing

- Model accesses can be more efficient and less complex during non-cryogenic tests (air mode)