LAT Engineering Meeting

20 April, 2004

TKR and LAT Survey and Alignment Planning

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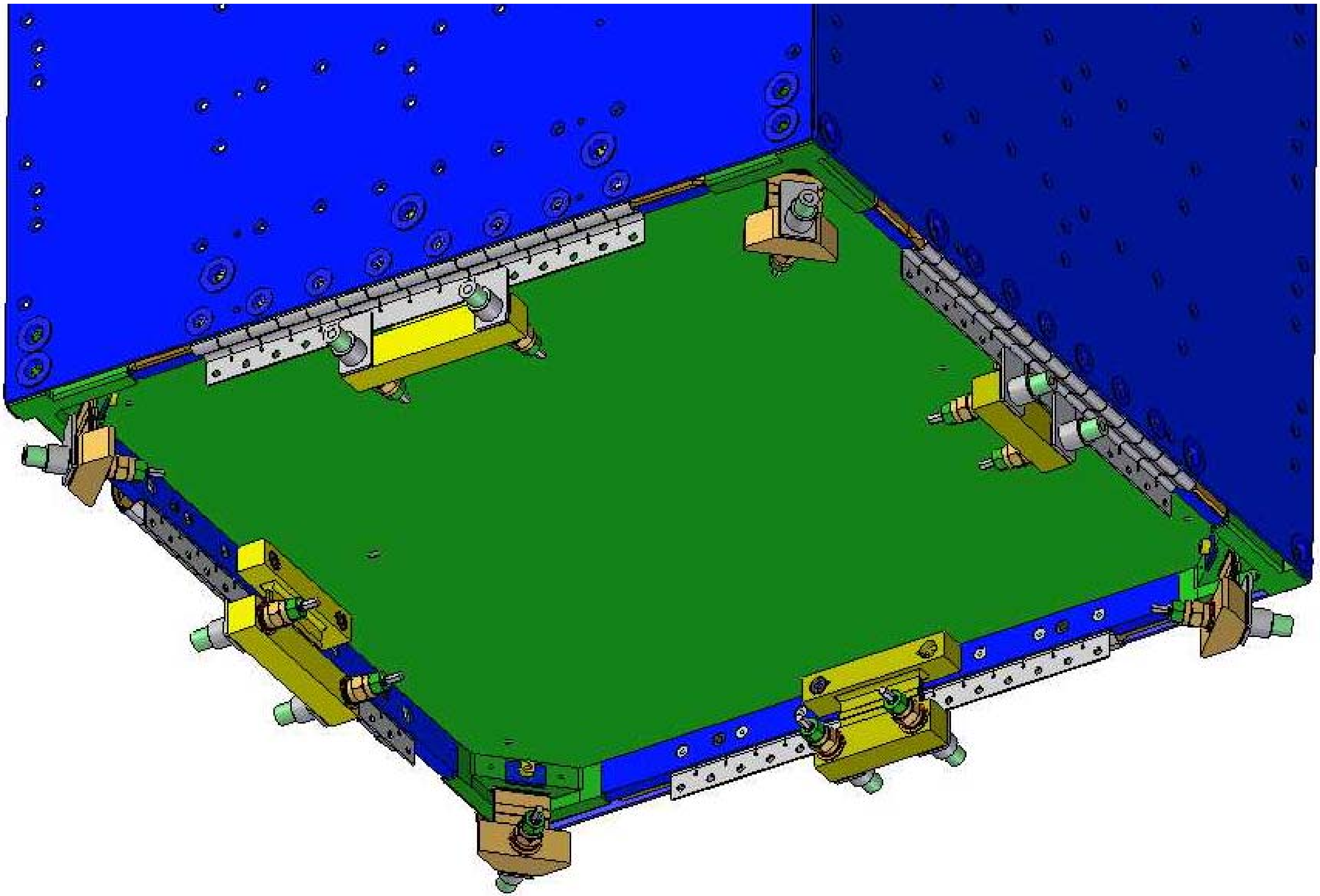
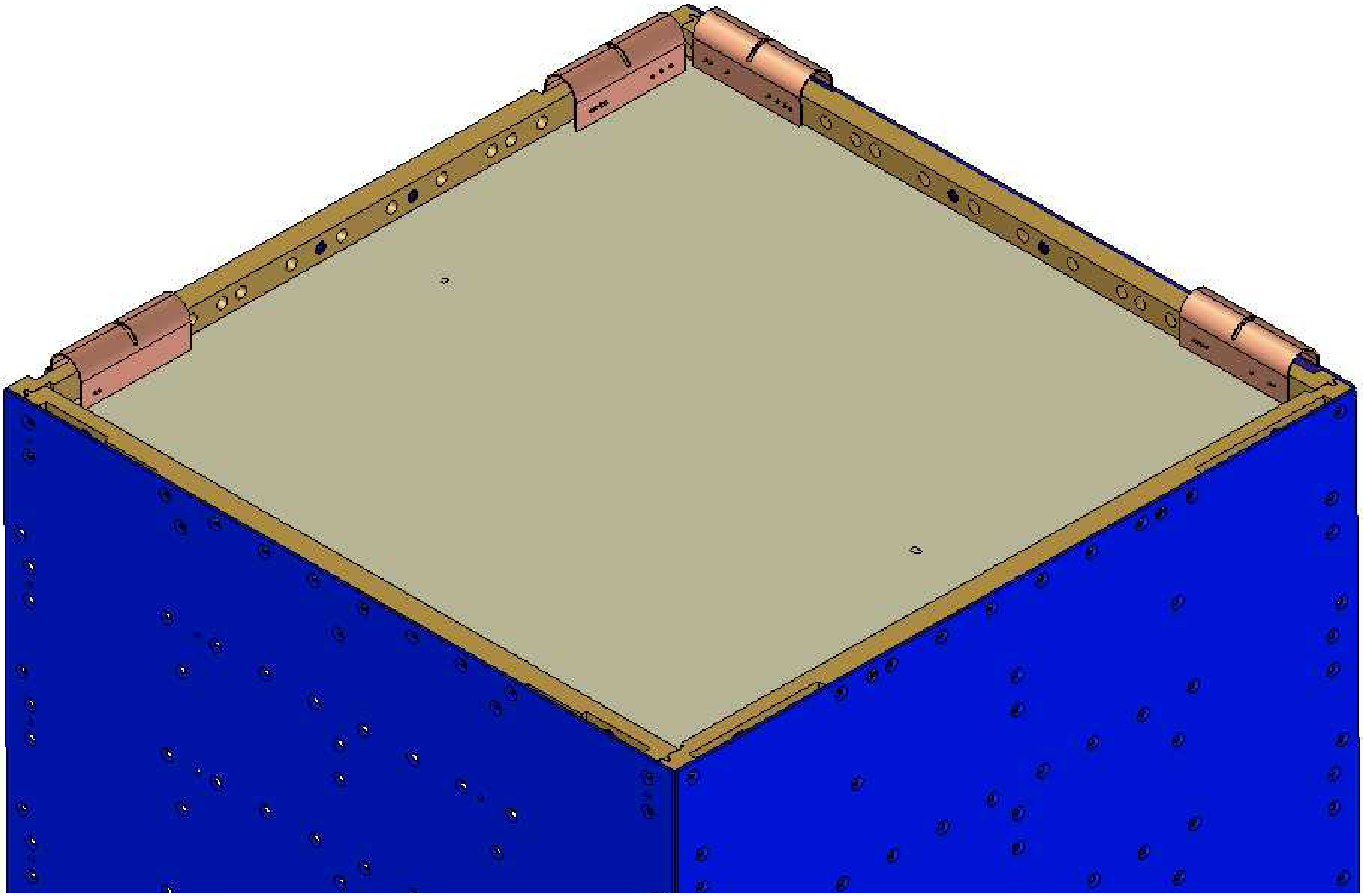
Agenda

- Overview of the TKR and Grid designs
- Rationale for Going to all the Trouble
- Overview of Measurement and Survey Flow
- TKR Assembly and Alignment
- LAT Integration Surveying

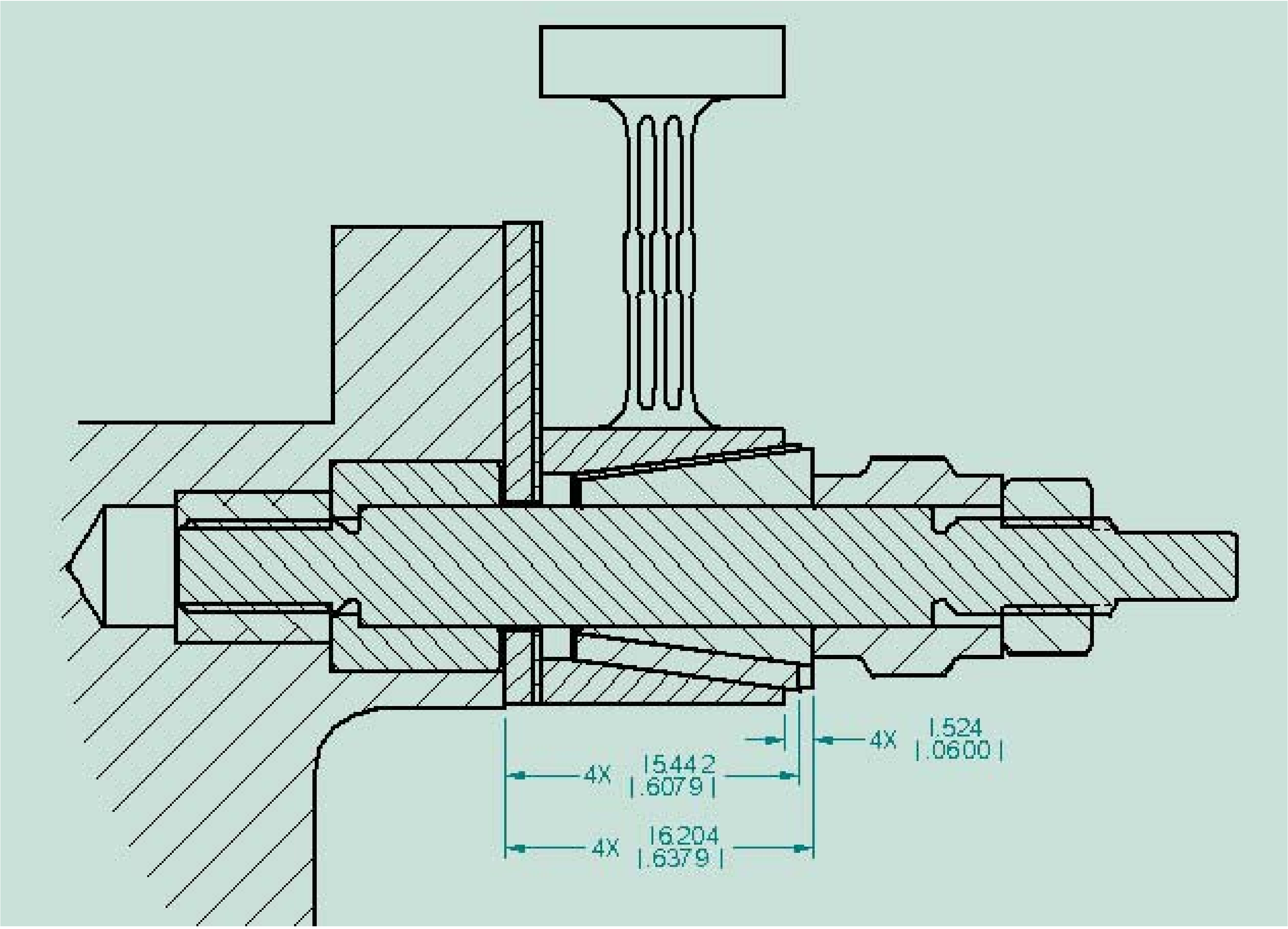
TKR Module Bottom



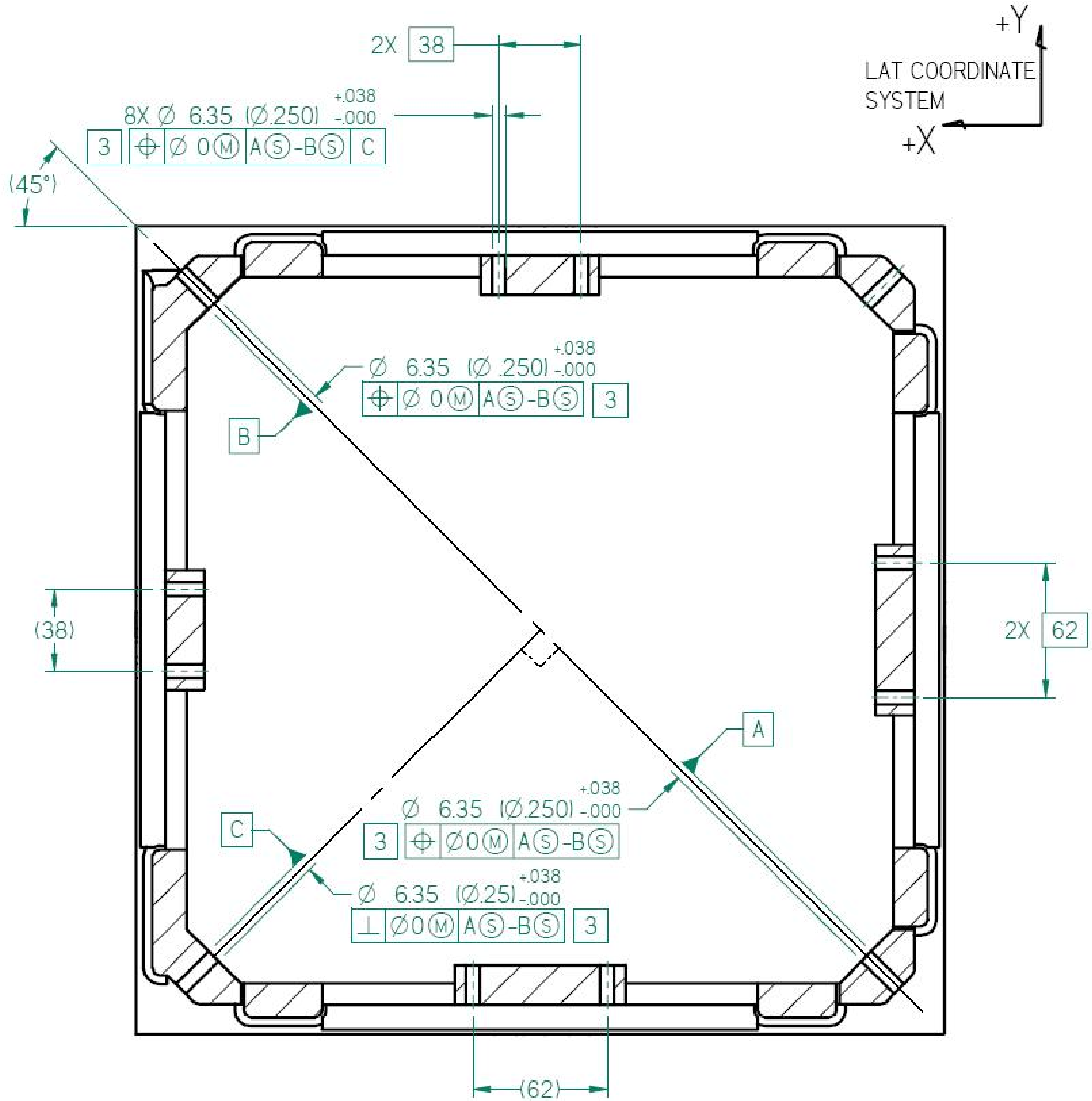
TKR Module Top



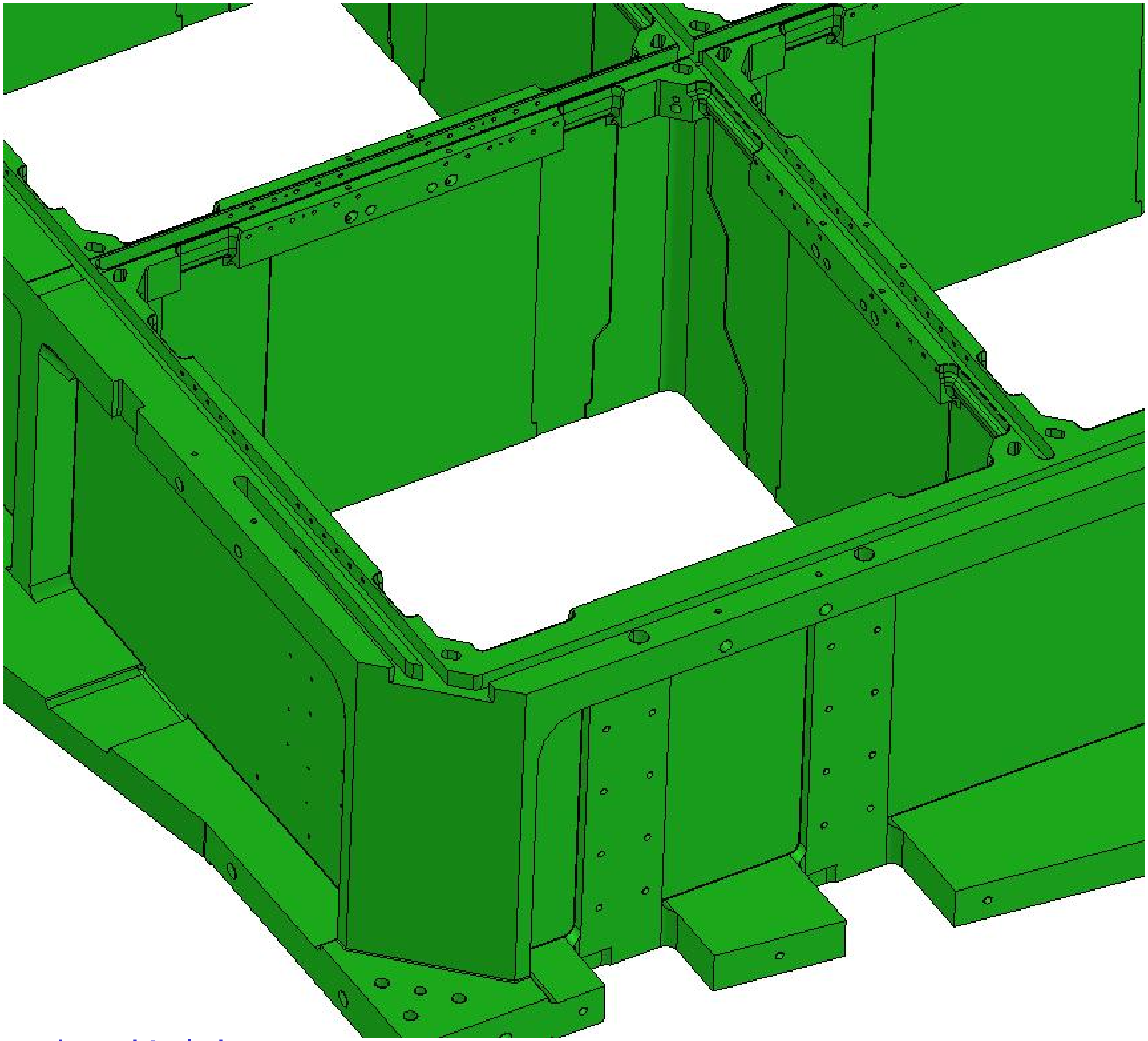
TKR Flexure and Eccentric Cone Section View



TKR Interface Definition



Grid Bay Design



Why all the fuss?

- **Why do we need to go to all this trouble to survey the TKR modules?**
  - **"why not just bolt it together and check it with feeler gauges?"**
  - **"all we care about is to make sure we have enough gap to handle launch motions"**
  - **"we do all of our alignment on-orbit anyway, so what good does surveying do on the ground"**
- **In principal, the LAT *requirements* for alignment are relatively loose. They are:**
  - **Ensure that TKR modules do not "collide" during launch → could be done using feeler gauges after completion of integration on the Grid**
  - **Align the TKR modules to within 30 arcminutes of the "LAT boresight" → could be measured with a precision level**
  - **Verify that the LAT is within its stayclear as defined by the LAT-SC IRD and ICD → could be done with tape measure**

- **So why are we going to all this trouble?**

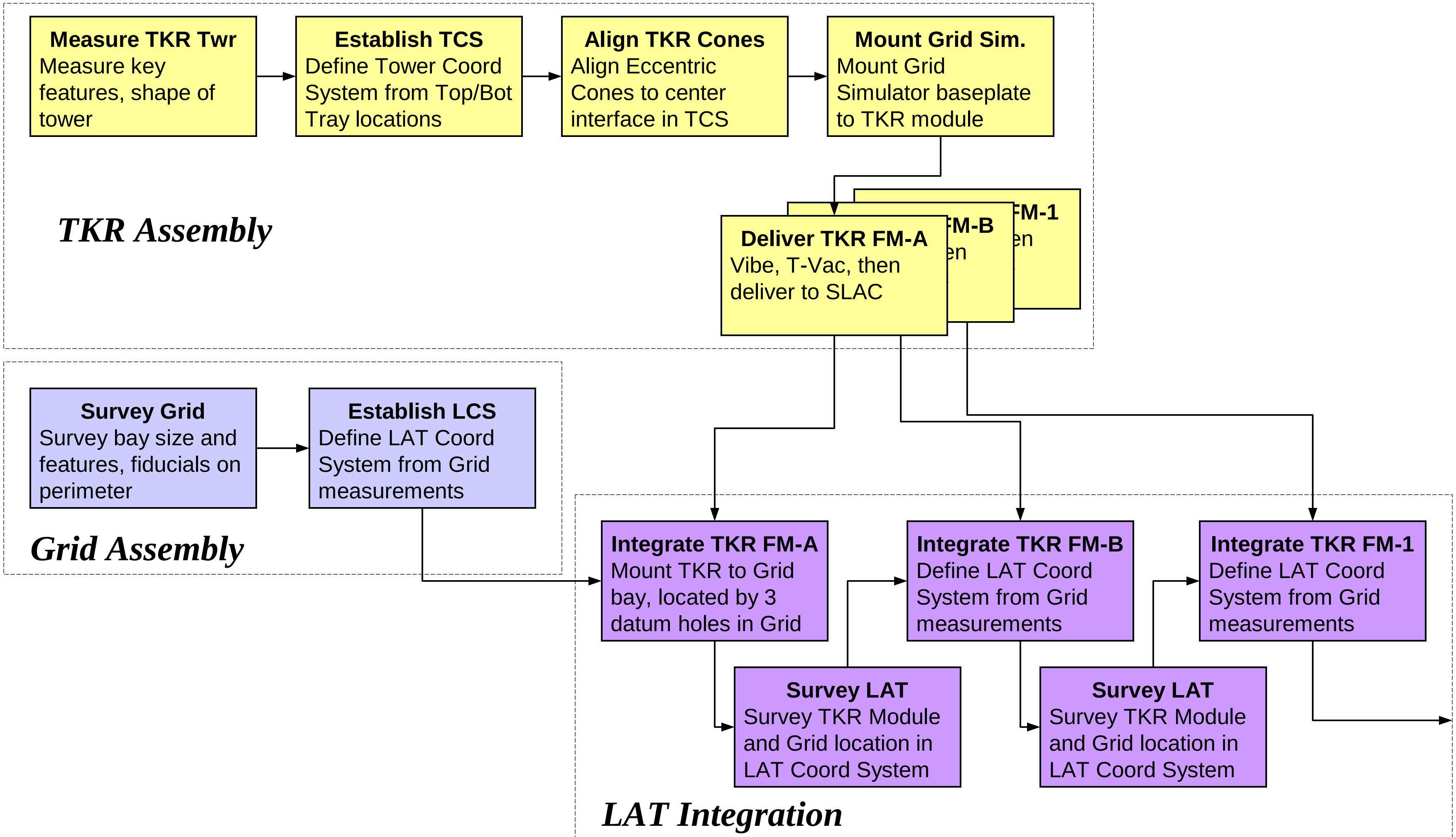
Why all the fuss ? — part II

- Why can't we use feeler gauges and levels?
  - In practice, using feeler gauges and levels would require waiting until the LAT hardware is largely integrated (Grid fab'd, TKR's mostly assembled and integrated)
  - Feeler gauges and levels produce measurements that are just relative to something else, so they provide little insight (knowledge) into how to resolve a problem if one arises
  - For both the TKR and Grid, the hardware design and assembly plans carry with them relatively large tolerances (relative to the gaps we are talking about)
- Here are a few of the design "features" of the LAT that result in these tolerances and gaps:
  - The LAT was designed to reduce dead space and gaps, and maximize coverage → the result is that gaps between elements are small
  - The Grid is not a stable optical-bench type reference structure → if it were, we would have a common reference point for many simple measurements
    - Tolerances associated with locating each of the bays on the Grid are large relative to the clearances we must maintain
    - The Grid itself bows under load, and the bowing may vary with orientation
    - The Grid and integration M-GSE provide no "absolute references" to which we can measure everything (and we can't afford a 27 cubic meter Coordinate Measuring Machine)
    - The LAT does not have a "bore" to define its "boresight" so it must be developed analytically
  - The TKR design leaves little room for error, literally
    - TKR hardware nominal dimensions use nearly all of its stayclear, with very little allowance for fabrication and assembly tolerances
    - There are many tolerances associated with Tray and Tower assembly, and they often sum together to define the worst-case size and location → even with RSS summing, these tolerances are large, relative to the gap sizes we are talking about
    - TKR mounting features (flexures with conical holes) can not be positioned suitably well to ensure that the TKR module is positioned within its stayclear → (actually, it's not even close)

What does the survey program buy? (risk reduction and knowledge)

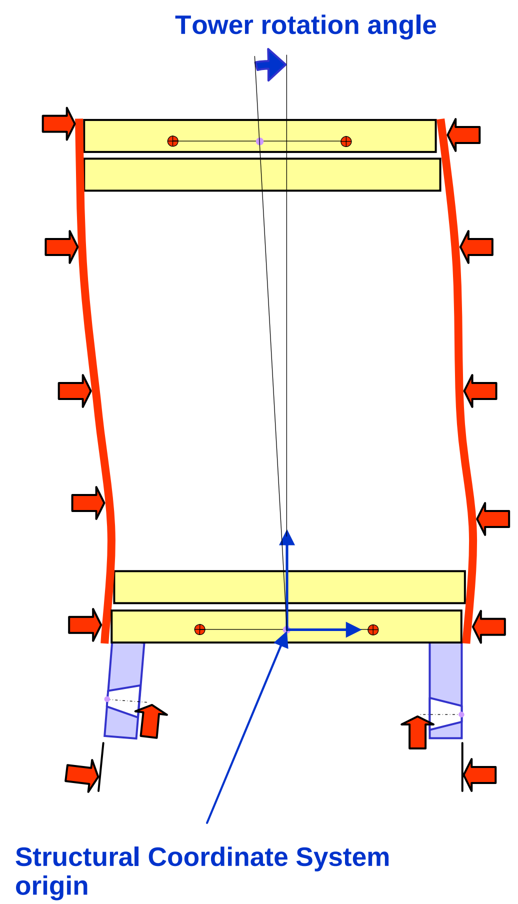
- Risk reduction
  - Our design results in two key risks
    - There is considerable risk that TKR modules will arrive that would not fit within their stayclear, when mounted using a hard-mounted, “bolt and forget” interface
    - Given the design of the Grid, there are few advance measurements that could be taken to tell us if we would be in trouble
  - The survey program addresses these risks
    - Alignment to balance out TKR assembly errors
      - As-built TKR modules are inspected at INFN-Pisa after assembly and a best-fit shape and orientation are established → this corrects for tower shape and size errors, as well as tolerances in positioning the flexures
      - The TKR flexure interface is aligned so it is centered on this best-fit shape → this results in the smallest possible “footprint” for the module in an “ideal” bay
    - Surveying of the Grid to establish an ideal LAT Coordinate System and “LAT boresight”
      - The actual Grid will be surveyed to measure the position of all 16 bays, and a boresight established that minimizes the tolerances for any given bay
      - This will provide a unique, fixed reference system for all LAT measurements
- Knowledge
  - No knowledge needed?
    - Our alignment requirements do NOT require any collection of as-integrated positions
    - Our design presents few features that have “built-in” references
  - The survey program will provide significant early information
    - TKR alignment data will provide ideal position information with which to diagnose and correct problems during integration
    - Post-integration surveys will provide actual vs expected position and gap comparisons that can be used to verify the integration process

Measurement and Survey Flow



Measure Tracker Tower

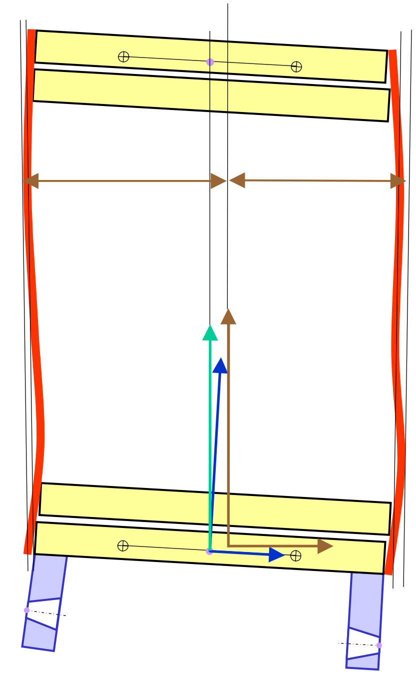
- Tracker tower is assembled upside-down at INFN-Pisa
  - Trays are positioned using an external alignment jig
  - Tower Sidewalls are mounted and bolted torqued, then jig is removed
  - This done while the tower is sitting on the CMM table
- Tower is then inspected using the CMM
- Features captured by CMM measurement
  - Datum reference holes in the top and bottom tray
  - Sidewall surfaces
  - Sidewall washer locations
  - Flexure locations
  - Flexure conical hole centerlines
- Define a “Structural Coordinate System” using locations of reference holes in the Bottom Tray only



TKR Tower Measurement (shown in right-side up orientation)

Establish Tower Coordinate System

- Calculate the pitch and yaw tower rotation matrices, based on the measured position of the Top Tray with respect to the Bottom Tray
- Transform the Structural Coordinate System by applying these rotation angles
  - This effectively "rotates" the tower such that the Top Tray is directly above the Bottom Tray
- Calculate the X and Y translation required to center this rotated coordinate system
  - Develop best-fit planes for each tower Sidewall
  - Establish a centerline from these best-fit planes
  - Calculate the offset between this centerline and the rotated centerline of the Struc Coord Sys
- Translate the rotated Struc Coord System
  - This effectively "moves" the tower, so it is centered on this centerline
  - The resulting coordinate system is defined as the Tower Coordinate System



BLUE Structural Coordinate System, centered on Bottom Tray

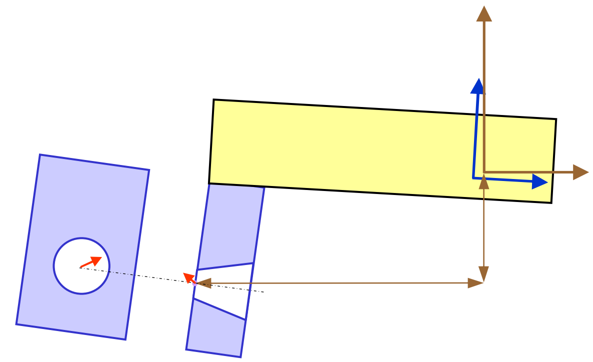
GREEN Rotated Struc Coord System to align Top and Bottom Tray

BROWN Tower Coordinate System: rotated and translated Struc Coord Sys to center it on best-fit tower shape

Tower Coordinate System

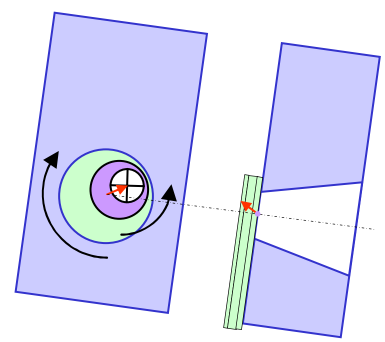
Align Tracker Eccentric Cones

- **Measure the location of the Flexures in the new Tower Coordinate System**
  - **This can be a new measurement or transform of the original data into the new coordinate system**
  - **Find "Flexure Point" locations, defined as the intersection of the cone centerline and the plane of the outer face**
- **Calculate the required Eccentric Cone travel and Shim thickness**
  - **The new Tower Coord System defines the best location for the real tower in an ideal Grid bay**
  - **Now the cone interface on the flexures needs to be positioned, so that it is located in its correct location for the "best" tower location**
  - **Cone offset = measured position – nominal values from design drawings**
  - **Cone travel is figured out by converting the cone offset from cartesian coordinates to cylindrical coordinates centered on the Flexure**
  - **Shim thickness is the Z coordinate**
- **Compare required travel with available travel to ensure that all cone have adequate capability**
- **Install and rotate Eccentric Cones at the 3 interface reference points at 3 of the 4 corner Flexures**



Face-On View **Side View**

Flexure Point locations in the Tower Coordinate System



Eccentric Cone travel is set by rotating cones and moving centerline of cylindrical hole

Eccentric Cone Alignment

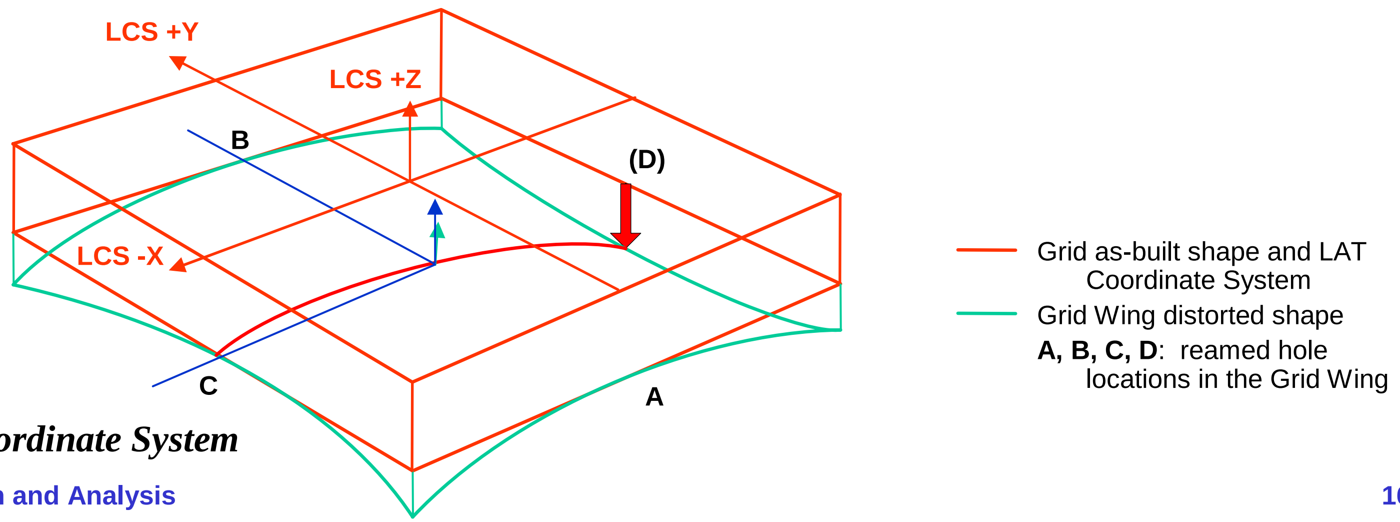
TKR Assembly and Alignment Re-Cap

- The final step in the TKR alignment process is to measure the offsets of tooling balls on the Top Hat Survey Fixture from the TCS origin
  - This information is needed so the location of the TCS and its origin can be reconstructed using only the locations of the tooling balls

- Re-cap
  - The Tracker module is assembled and cones aligned at INFN-Pisa
    - All dimensional and interface verification is completed in Italy
    - All of this work can be repeated at SLAC, if needed or desired for checking
  - All Tracker module alignment work is done so as to center the actual TKR module and locate the interace such that it would be centered on a perfect Grid Bay
  - Tracker alignment does NOT NEED to accommodate any Grid hole errors
    - Grid tolerances are external to the TKR and have no impact on the alignment of the TKR
    - Some TKR Eccentric Cone travel must be preserved to accommodate Grid hole locations, but not for the 3 interface reference Flexure Points at the TKR corners
  - Tracker Eccentric Cones can be re-rotated at SLAC
    - If cones become unseated, dropped on the floor, and run over by a truck, new cones can be inserted and their offsets dialed in using the same offset calculated in Italy
  - Tracker modules DO NOT need to be moved while on the Grid
    - Eccentric cones do not need to be rotated *in situ* with the TKR hanging off them

Survey Grid and Establish LAT Coordinate System

- **Dimensionally inspect the Grid**
  - **Measure bay features with respect to the perimeter datums on the Grid**
    - **Features include top flange cut-out, TKR mounting holes, CAL datum pins, etc**
    - **This measurement could be based on inspection data from the Grid machine shop, or a new inspection done at SLAC**
  - **This measurement could be done on a CMM or using laser tracker system**
    - **Laser tracker can be thought of as a portable CMM with slightly reduced accuracy**
    - **Either way, the Grid fiducial locations need to be measured**
- **Define LAT Coordinate**
  - **Locate the center of the LAT Coordinate System (LCS)**
    - **Nominal location is at the center of the Grid top flange**
    - **As-built location could be defined by finding the centers of as-built bays or the center of the SC Flexure mounts, …..**
  - **Establish master tooling ball locations and offsets that will preserve the LCS independent of Grid sag (marked at locations A, B, and C in the sketch)**



Grid and LAT Coordinate System

Survey TKR Modules on the LAT

- Survey the location of the Grid in the room
  - There are reflector ball mounts throughout the room that are used to develop a surveying network
  - The Grid reflector ball locations are measured from various locations in the room and the location of the LAT Coordinate System in the room is reconstructed, using offset information from prior surveys
- Survey the location of the TKR Module
  - Mount the Top Hat Survey Fixture and survey the location of the reflector balls
  - Factor in offset data of Top Hat to Tower Coordinate System offsets to calculate the location of the module’s Tower Coordinate System with respect to the LAT Coordinate System
- Calculate TKR Module relative positions
  - Compare the as-installed TKR module location with respect to expected nominal values, based on the Grid survey bay offset data
  - Compare this location with respect to neighboring towers to fine as-integrated pitch between TKR modules
  - Combine surveyed TKR location with TKR as-built form measurements to evaluate TKR gaps
    - This can be compared with feeler gauge measurements where neighboring towers are integrated
    - At the bottom of the TKR, this information is needed because feeler gauges don’t reach

Conclusions

- The survey program significantly reduces schedule risk by ensuring that TKR tower shape and position is measured in Italy—at the source—and all corrections are made and measured there
- Surveying on the LAT provides tower-by-tower information about TKR tower locations and fit, and provide immediate verification of fit and form for each bay without needing neighboring tower in place