A Fresh Look At Hangar Design

A new 200,000-sq.-ft. maintenance hangar is the centerpiece of Northwest Airlines support and service efforts

By Sofronio C. Mendez, P.E.

THE NEW NORTHWEST AIRLINES MAINTENANCE FACILITY IN DULUTH, MN is the airlines most important project constructed to date. The facility will provide heavy maintenance "C" and "D" checks for Airbus A320 and Boeing 757 aircraft with the capability of servicing wide-body aircraft if needed. In short, the new facility is critical for keeping the airlines planes in the air.

The new facility includes: a large hangar; shop areas; engine plant; and a materials operation that stores and distributes materials to the hangar, shop and line operations.

For this facility, rather than concentrate solely on the hanger portion of the project, the design goal was to consider the hangar area and direct support shop activities as a single unit. This approach simulated the techniques of flexible manufacturing and the concept of common use work cells or work cell groupings, with the intent of increasing equipment utilization, reducing building square footage and increasing efficiency of operations.

The key structural element to the project was designing a roof structure that would resist heavy snow loads with icing effect, large horizontal forces due to wind exposure of the huge building envelope, and uplift forces generated by the design wind speeds when the hangar doors are in the open position.

In addition to the customary design loads for the roof structure, additional criteria included: compatibility with aircraft clearances; ability to support a full-coverage 5-ton bridge crane; rapid speed of erection; minimum weight structure; architectural envelope that will reduce wind forces; structural geometry that would not interfere with aviation clearances; low maintenance requirements; and roof slope geometry that optimized roof drainage requirements.

Alternate concepts were studied using computer models. The concepts were evaluated using a comparative system analysis that quantified the following: weight of steel per square foot; erection time; door deflection criteria; building wind envelope; building wind envelope; resistance to large-scale horizontal torsion stresses due to design wind forces; and foundation system resisting uplift and horizontal forces. In addition particular attention was paid to accurate prediction of vertical movement of the structural element above the hangar door, since this would effect the efficiency of the motorized door system.

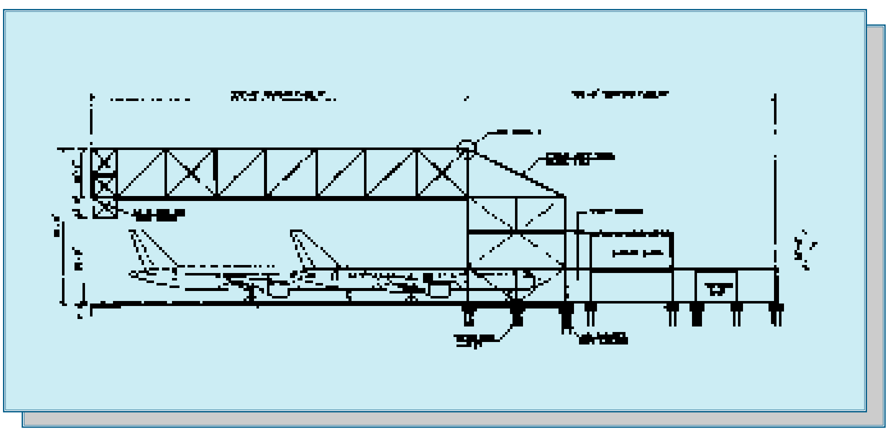
Structural System

The selected concept is a two-way structural support system for the hanger roof and a conventional steel framed with concrete on metal deck floor system for the two-story support facility structure. An expansion joint is provided between the hangar and support facility to minimize additional thermal stresses. The support facility has its own bracing system in resisting lateral forces in the North-South direction, with a portion of its East-West lateral resistance derived from the hangar structure.

VERTICAL LOAD SYSTEM

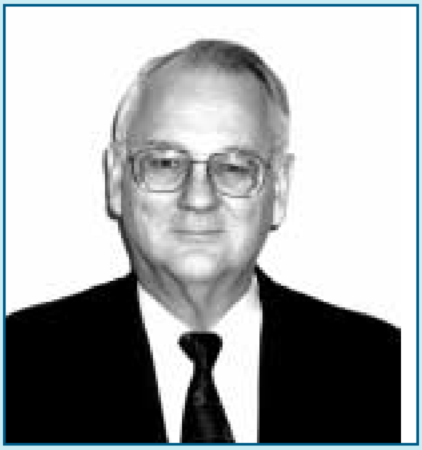
The roof structure is designed as a two-way vertical load carrying system. A box truss spans 315' across the front of the hangar, creating a full-width opening. Four trusses span 230' from front to rear of the hangar structure distribution roof and crane loading between the box truss at the front and the braced bays at the rear of the structure. Structural steel weight and box truss deflection are design parameters that were minimized by creating a cantilevered action in these four trusses. The cantilevered action was provided by a tension tie member that transferred top chord tension forces to column in the 60'-deep braced bay. The resulting cantilever trusses actually behave as propped cantilever trusses with inflection points located approximately 160' from the box truss. The tension force in the tie member creates an uplift condition on the column of the braced bay. The tension is resisted by rock anchors installed through the pile cap and anchored 15' into the granite bedrock at a depth of 10' to 25'. Uplift on the column under normal working conditions was minimized by framing the concrete second floor so that girders are supported at the uplift columns.

Cantilever trusses are designed with two different depths to accommodate the position of the truss with respect to the required slope for roof drainage. Depths are 26' and 28'. Truss panel sizes are chosen as 30'-9". The cantilever trusses are designed to accommodate loadings for snow and ice per the Minnesota Building Code, mechanical equipment located at



HANGAR COST SAVINGS

By Larry Kloiber, P.E.



THE LOW BID OF $4.5 MILLION FOR THE STEEL PACKAGE ON THE NORTHWEST AIRLINES MAINTENANCE AND ENGINEERING FACILITY IN DULUTH, MN, WAS $500,000 OVER THE PRELIMINARY BUDGET. As a result, the airline opted to reduce the scope of the project and also to ask LeJeune Steel Company to submit cost reduction proposals to the project's construction manager, McClier.

The scope reduction, which deleted provisions for a future second floor, along with 14 proposed modifications, generated $300,000 worth of savings.

- Change roof deck finish. The roof deck finish was changed from a G90 galvanized to standard grey paint. Since the entire roof interior was field painted white, there was no change in final appearance.
- Special design of joist and joist girders. The joists and joist girders were conservatively sized as standard uniformly loaded SJI designs. McClier was able to supply the special bridge crane and snow drift loads so it was possible to custom design for exact load conditions, which saved 30 tons.
- Eliminate sub-framing in trusses. The roof trusses were designed with double angle braces midway between panel points to reduce minor axis slenderness and save overall weight. LeJeune did a labor-vs.-material cost study and determined it was less expensive to increase the sizes of some of the main members, thereby eliminating the shop and field labor associated with the braces.
- Revise vertical bracing. The vertical bracing for the hangar was designed as tension members in a X pattern. Cost studies indicated single diagonals designed for both tension and compression would be less costly to fabricate and erect.
- Use of oversize holes for trusses. The roof trusses were specified to be high-strength bolted with standard holes. This would have required full shop assembly of trusses up to 30' deep and over 200' long. The use of oversize holes resulted in a significant savings compared to the cost of assembling, drilling the holes and then disassembling to ship—along with the impact of this procedure on the project schedule. It was determined that by using 1"-diameter slip critical A390 bolts in oversize holes along with special dimensional checks and limited sub-assembly checks, all of the truss members and gusset plates could be drilled on the CNC drill line.

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the truss bottom chord level, and two crane systems with interlocking capabilities suspended from the truss bottom chord.

The box truss is comprised of two parallel trusses 42' deep, spaced 15' apart and cross braced together at the four locations where the cantilever trusses intersect. The box truss spans 315' across the main chords of the cantilever trusses, which presented a challenge to incorporate the multiple functions of some elements. This was accomplished by creating a double level bottom chord that functioned coincidentally with the bottom chord lateral bracing system and the vertical box truss system.

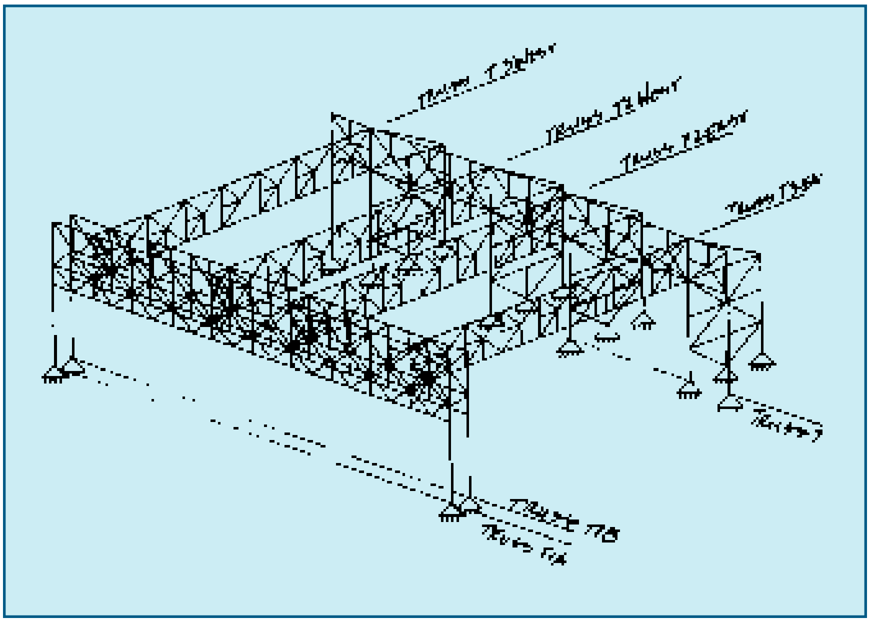
The sequence of tightening the connections between the box truss and supporting columns was a critical erection concern because the box truss is supported on slender columns. To prevent secondary stresses in the supporting columns created by the initial rotation of the box truss ends, bottom chord connections were not tightened until all gravity loads were applied to the structure.

Sub-framing in the form of joist and joist girder were used to support the roofing system. Bottom chord framing was provided to support moving cranes and mechanical catwalks. The diagonal bracing at the bottom chord level of the trusses serves as a diaphragm, reacting with the steel roof deck in resisting longitudinal and transverse wind forces. The diaphragm transfers all the lateral forces to the vertically braced frames at the perimeter and interior of the building.

The maximum vertical deflection is reflected in the mechanical connections at the top of the hangar door. These deflections are accommodated by a piston in the door mechanism that accommodates vertical movement.

Of utmost importance to the design and constructibility of the truss system was the connection detail at the top and bottom of the exposed tension struts. The design force in each tension strut is 1000 kips, which must be transmitted to the vertically braced frames inside the support facility.

Of equal importance is the detailing of the box truss girder—specifically, making sure that distortion of the truss cross-sectional geometry is minimal to take advantage of its full vertical load-carrying capacity. Two-way bracing was utilized to achieve the required stiffness. Because of the possibility for cumulative joint movement contributing to the truss deflection, all of the bolts were fully tensioned using load indicator washers.



Lateral Load System

The hangar lateral bracing system is symmetric in the North-South (front-to-rear) direction and asymmetric in the East-West (side-to-side) direction. Lateral bracing bays are positioned on three sides of the structure, the rear wall and the two side walls, plus the four braced bays that are part of the cantilever truss system. This system allows the front wall of the hangar to be free of braces and maximizes the available floor space for aircraft positioning. The side walls are braced with two-bay-wide vertical bracing systems. The rear wall contains two single-bay bracing systems connected at the top by a vertical truss along the top of the rear wall. Together, the system acts as a rigid frame in transferring lateral loads to the foundation.

Lateral loads in the North-South direction transfer to the two side bays and the four braced bays through the girt system, roof deck diaphragm, and the bottom chord bracing system.

Lateral loads in the East-West direction are transferred to the braced truss-frame at the rear of the hangar through a translational mode, and to the side braced bays through a torsional mode. The load pathflows from the girt system of the side walls

Details To Simplify Erection

By Larry Kloiber, P.E.

THE PROJECT SPECIFICATIONS REQUIRED THE FABRICATOR TO BE RESPONSIBLE FOR THE DESIGN OF THE CONNECTIONS. However, LeJeune Steel Company's (LSC) policy is to develop connections and submit these sketches and calculations to the engineer of record for approval, as per the AISC Code of Standard Practice. Because the airline would not waive the connection design requirement, LSC retained Computerized Structural Design (CSD) to design connections based on the provided forces.

The detailing phase of the project began with a meeting attended by the owner, structural engineer, connection design engineer, steel detailer, steel erector, joist supplier, deck supplier and LeJeune project management, engineering and operations personnel. Basic connection concepts, design and approval processes, material specifications, and construction sequences were all discussed and agreement was reached.

Connection design and detailing was a team effort involving CSD, Computerized Detailing Inc. (CDI) and LSC. The process started with the project structural engineering preparing the design forces for all of the connections. LSC then proposed various types of connections for each member. CDI prepared connection sketches showing the geometry and preliminary details. LSC reviewed these sketches for constructability and economy and forwarded their comments to CSD, who sized all elements of the connection and made any required structural modifications. CDI then used these design sketches to detail all of the connections, which CSD then reviewed and approved. These connections were also submitted to McClier for approval as the engineer-of-record.

In developing connections, in addition to the normal goals of structural integrity and fabrication economy, a special effort was made to simplify erection. Because of the complexity of the framing, and the anticipated conditions at the site, it was determined that the major slip critical connections should be made on the ground. Any connections that needed to be made in the air required the use of 90' aerial lifts operating on rough ground. It was decided to make all major truss member bolts independent of any sub-framing connections. This was accomplished by field bolting sub-framing such as bracing to connection plates shop welded to the main truss gusset plates. The bolts in the gussets could be tensioned and inspected before the trusses were erected. All of the main roof trusses also were detailed to minimize bolt requirements. Chord members were upsized to make it possible to splice at alternate panel points. Splices were located at panel points to utilize gusset plates and bolts already at these points. Compression chords were finished to bear to reduce bolts needed for these splices.

The bottom chord bracing system consisted of W14 struts and WT diagonals in an X pattern. The struts were detailed in 60' lengths to eliminate splices. The WT diagonals were originally oriented with the stems up. The engineer was able to review crane clearances and allow the WTs to be detailed back-to-back and eliminate the center splices.

The most critical and complex connections in the hangar are the connections in the main roof trusses to the supporting jack trusses at the front and rear of the hangar. The large connection forces at the front box truss assembly made it necessary to increase the size of the truss verticals in order to utilize double gage lines to install all of the required bolts.

The roof trusses were designed with fixed supports at the rear of the hangar. In order to transfer the large tension forces through the supporting columns to the tension tie, the columns were rotated 90 degrees. This allowed the use of gusset plates on the flanges to transfer the tension to diagonal while also transferring the vertical reaction to the column flanges.

The continuous truss at the rear supports joists at both the top and bottom chords. Because of the continuity and the short spans, the truss member forces were relatively light. It was decided to rotate both chords to allow the joists to bear on the top flanges.

The side wall columns were W36 sections over 90' high. These columns were mill ordered full length and fabricated without splices to facilitate erection.

CSD sized all detail material and connectors along with checking members for net section, block shear, bearing, etc. Gusset plates were checked for tear out and buckling. Complete design calculations were furnished to the engineer for review and approval.

The project specifications also required the erector to prepare a detailed erection plan showing the assembly, hoisting and bracing of the hangar steel. L.H. Sowles Company, the erector, prepared a detailed assembly and hoisting plan and retained Clark Engineers to design the shoring and guying system. CSD checked erection stresses for the roof trusses.