HOT WINGS

Flexibility was key in the design of this huge painting facility for airplane wings

By William Mazur, P.E., and Randy Carwile

AS THE BOEING COMPANY WORKS TO SOLIDIFY ITS POSITION AS THE WORLD'S PRE-EMINENT COMMERCIAL AIRCRAFT MANUFACTURER, flexibility to allow future production improvements are a primary requirement for any new construction. The company's latest aircraft is the Boeing 777, and among the structures designed to accommodate construction of this plane is Building 40-37, an 18 million cubic ft. state-of-the-art facility for cleaning, sealing and painting aircraft wings.

Production demands included space requirements for horizontal wing laydown and body section booths to perform the sealing, testing and painting operations. Also required was a vertical wing position booth for cleaning and painting and a complete complement of horizontal booths for applying corrosive inhibiting compounds for both wings and body sections. Traveling/moving roofs were required over the horizontal and vertical wing laydown booths to facilitate a heated air curing cycle. Additional areas also were needed for smaller part handling and storage.

While the basic building footprint of 400-ft.-by-454-ft. was decided upon early in the program development, the final layout and method of operation will continue to evolve for years to come. Flexibility and the ability to accommodate future modifications, therefore, were key to the success of the design. Three major requirements also significantly impacted the design:

- A requirement for an elevated (26-ft.-4-in.) first floor with no bracing, which created a soft story;
- The need for an airlock structure to transport large aircraft sections to and from the assembly area, which interrupted the west support tower and produced an irregular shaped structure; and
- A requirement for an overall building height more than 100 ft. above grade.

PROCESS SYSTEM CONSIDERATIONS

Building operations on the $90 million structure required up to 1.6 million cu. Ft. per minute of tempered air to move through the building. As a result, the roof framing system had to support 1,800 kips of process equipment and utilities, 425 kips of roof-top HVAC units, 680 kips of process exhaust systems and 800 kips of architectural components, such as elevators, smoke curtains and smoke vents. All together, the combined 3,700 kips was the equivalent of seven fully loaded 777 aircraft stacked on the roof of the building.

Process design required very large aircraft components—some weighing as much as 40 tons—to be handled in the entire open factory area, as well as entering and exiting through the airlock structure. A series of 40 ton trolleys operating on an underhung bridge crane system in the 354-ft.-by-400-ft. column-free manufacturing space met the processing needs. The design challenge, however, was to locate columns only in the two 50-ft.-wide tower structures.

Additional process equipment required a 25-ft.-deep basement beneath the entire structure. As a result, the ground level floor became an elevated slab, yet it still had to be capable of supporting HS20-44 loading.

Structural System

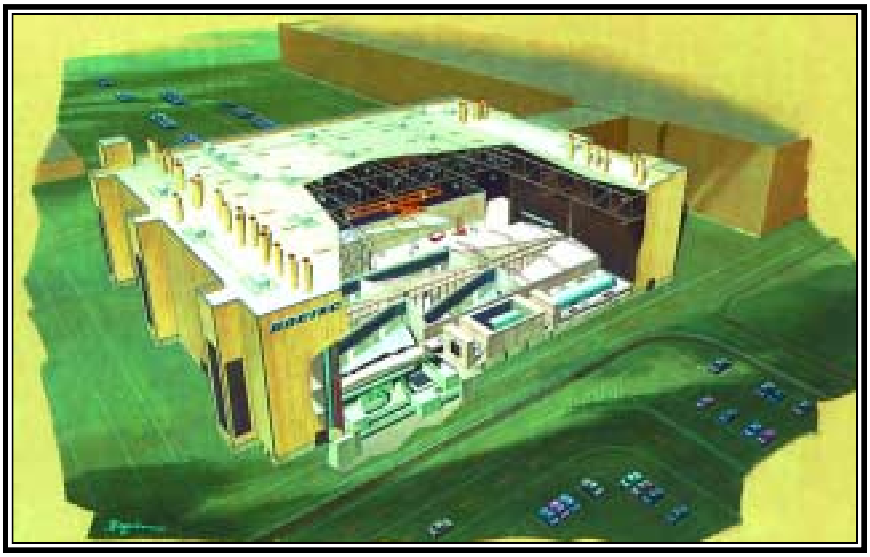
The building consists of two 50-ft.-by-400-ft. tower structures in the north-south direction connected by five Pratt trusses spanning 354 ft. The top and bottom chord of these trusses are composed of W14x605 (ASTM A572 Gr. 50) sections. Column connections of these Pratt trusses are capable of resisting more than 1,800 kips of vertical force and require 116 slip-critical connections.

The trusses are 100 ft. on center and are connected by a sub-truss system at 25 ft. on center. Lateral resistance is achieved in both the north-south and east-west directions by ordinary moment-resisting frames (OMRF) with a soft story. Concentric Chevron bracing is provided from the second floor to the truss bottom chord. All chevron bracing was designed for one-and-a-half times the prescribed analyzed force in accordance with Uniform Building Code Section 2710 (h) 4.

The Everett site is located along the Cascadia Subduction Zone seismic fault. This category III building is classified as an irregular structure with a soft story that required three dimensional dynamic analyses per the 1991 Uniform Building Code, Chapter 23, Part III. The main purpose of the 3D model was to recognize the impact on member sizes due to three dimensional redistribution, torsional effects and any load sharing effects.

All required modeling, analysis and design of the structural system were performed using STAAD III/ISDS structural software from Research Engineering, Inc. The seismic analysis methodology included:

- 2D models of the typical east-west and north-south frames incorporated all masses with exact geometry;
- Models were analyzed utilized the UBC normalized response spectrum and the equivalent force method per UBC Section 2334;



• P-Delta effects were considered in accordance with UBC section 2334;

• Preliminary member sizes were selected;

• 3D model was developed from information obtained in the 2D analysis;

• Utilizing the UBC normalized response spectrum, the model was analyzed in both orthogonal directions

• Accidental torsion was incorporated;

• Seismic base shears were summed and scaled up to 100% for an irregular structure and input back into the model and re-analyzed; and

• All girders-to-column connections were designed to resist the combined gravity load and 3(R_w/8) times the design seismic force. Design of the collector members (members that gather forces to complete the force path-to-bracing system) did not allow a one-third stress increase.

FINAL COLUMN DESIGN

The component most affected by the soft story is the main building columns. Because the first story has no bracing, the entire seismic force applied at the second floor is resisted by the 20 main building columns. Since the columns are required to resist lateral loads in two directions, a built-up cruciform-shaped column section using ASTM A572 Gr. 50 steel was required. Each column is composed of one W36x720 and two W14x311 members with 2-in.-thick cover plates. This composite section extends more than 50-ft. from the foundation pedestals and weighs more than 1,600 lbs. per ft. until it transitions to a W14x605. The story drift limitations conformed to UBC section 2334(h).

The lateral force is applied with a moment arm of 26-ft.-4-in. about the column base that, coupled with axial forces of more than 1 million lbs., produced extraordinary column bases. Base plates for these columns are 7-ft. square and 8-in. thick and are restrained by 12 5½-in.-diameter by 14-ft.-4-in.-long anchor bolts. Nuts for these anchor bolts weight 65 lbs. each. Base plates were founded on 15-ft. square concrete pedestals, 20-ft. above the 5-ft.-thick basement mat.

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