A Terminal For The New Millennium

Radical geometry, combined with simplified fabrication and errection techniques, created a strikingly beautiful and efficently functional terminal while meeting budget and schedule constraints.

By Paul Lew, Richard L. Tomasetti and Jay Prasad

Terminal One, the first new terminal at New York's John F. Kennedy Airport in a quarter century, features a unique balance of aesthetics, structural innovation and tight budgeting and scheduling. Carefully designed project geometry, together with simplified fabrication and erection techniques, allowed this high-tech project to be completed within budget and schedule constraints.

Part of this terminal's striking appearance is a result of the use of a radial geometry. The radial geometry resulted in the use of circumferential ringlike triangular truss girders. In addition, there are radial arch girders that although similar in geometry, still appear different. This difference occurs because the arch girders are intersected by a vertical front wall plane that makes each radial arch uniquely truncated. This geometric juxtaposition creates the great spacial diversity that makes Terminal

The new Terminal One is a consortium of Air France, Japan Airlines, Korean Airlines and Lufthansa Airlines and represents a renaissance for Kennedy Airport as the international gateway to America. The consortium, called TOGA (Terminal One Group Association), is unique in terminal privatization.

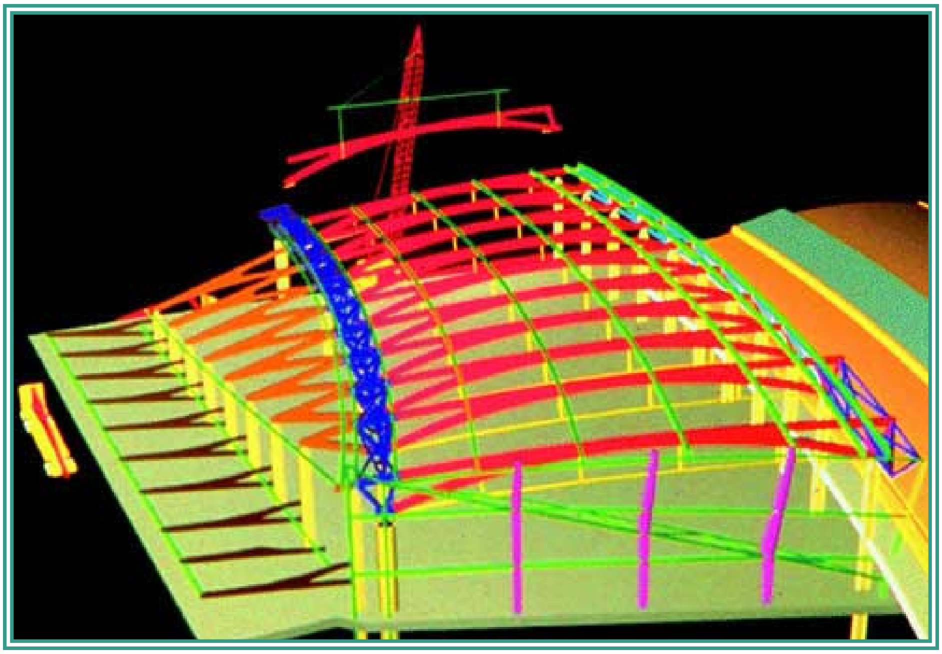
Geometry

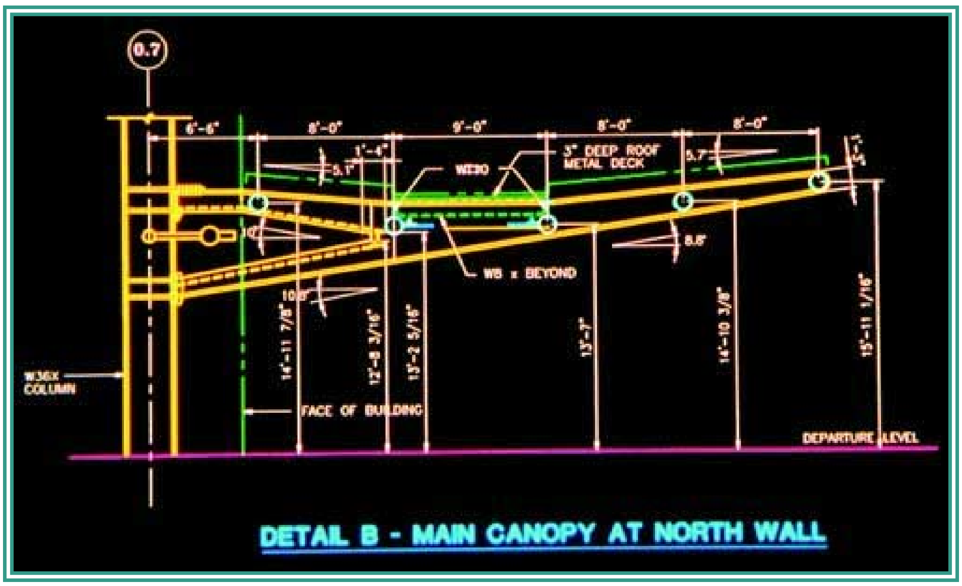
The high tech design of Terminal One is comprised of a complex spacial geometry that consists of the intersection of a torus (a donut shape) with a flat vertical wall plane along the entrance. The resulting plan maximizes the amount of circumferential perimeter for the plane loading gates while still providing a linear curb for cars and bus pick up and drop off. The vertical front wall intersection with the torus causes the vertical wall height to increase exponentially from the center to its ends. The inner continuous arches within the overall torus form reached spans of almost 130'. The end walls of the terminal lean out and spread out like the wings of a bird, further reinforcing the overall image of flight that the terminal epitomizes.

In plan the torus section represents one eighth of a full circle (45 degrees). In cross section the outer arch section is a small portion of a full circle. The cross sectional radius of the torus arch section is 780'. The first main circumferential plan grid radius is also 780'. The arches are placed on the polar grid at 1.82-degree increments. The distance between the arches is about 25' at the 780' plan radius and increases to 34' at the 1,020' plan radius.

The exponentially increasing height of the front wall caused by the intersection of the torus form with the vertical front wall plan is at its minimum height of 42' at the center of the wall and reaches a maximum height of 62' at the ends of the wall. This results in making the roof appear to hover over the main ticket lobby like a flying carpet. In addition to the front wall increasing exponentially in height from the center, the front wall column bays increase exponentially in width as well. This is a result of the straight-line front wall grid intersecting the plan's radial grid. Furthermore, the tubular geometry of the torus enhances the feeling of perspective inside the terminal as objects disappear from view faster due to the radial-circumferential grid rather than an orthogonal grid.

Equally spectacular to the roof structure are the sloped out end walls which start out vertical and then slope out along a





diagonal in the end wall elevation. The maximum slope out of the end walls is 18'.

Structural System

The ticket lobby is the grand space of Terminal One. The continuous leaping roof arches use a "pi" shaped box girder in cross-section to simplify fabrication. The "pi" shaped box girder cross-section allows the fabrication of the box girder while using only fillet welds. All details were developed with this approach in an aesthetic but cost-effective manner. Because the length of the main arches is over 120', they had to be shipped to the field in two pieces and welded together at their crown on the ground. By welding together the two half arches on the ground they could be welded under high quality control conditions. Even under these circumstances, the web connection at the midspan joint is bolted with the bolts hidden inside the box to prevent constraining the joint during welding.

Because of the large, unbraced web areas of the arches between the box top and bottom flanges, an analysis of web plate buckling was performed. Internal stiffeners were added to assure that the webs would not buckle. In the fabrication start up process, experiments were performed to determine what minimum thickness of web plate was required to prevent weld show-through. A minimum thickness of 3/8" was determined to prevent weld show through.

The climatic joint of the structure is the connection of the leaping arches with the curvilinear triangular pick-up truss girders. The bottom chord of the leaping arches has an end plate that bears on an end plate from a triangular yoke of the triangular pick up truss. The arch also has tie rods that have clevis connections to resist the arch thrust. The tie rods are attached on the ground before the arches are erected. The top chords of the continuous arches are in tension at the triangular truss supports. Because of the "pi" shaped top chord, a top bolted splice plate was used to connect the top chord to the triangular truss yoke. The top splice plate thus cannot be seen from the ticket lobby floor; and is part of the detailing approach to the connections which either hides bolted connections as much as possible or to glorifies them as is done at the arch bottom chord bearing connection.

The complete profile of the leaping arches is exposed to view with no beams framing directly into it. All roof beams bear on the top chord of the arches and are hidden from view by a ceiling. These beams had to torsionally stabilize the main arches and, as a result, an industrial framing system consisting of double cantilever girders over the arches with alternating infill beam spans was used. The girders of the double cantilever provided the rotational stability for the main arches by bolting the top flange of the "pi" shaped arch to the bottom flange of the cross beams.

The triangular pickup truss girders are curvilinear in plan and tilted in cross section so that the top plane remains tangential to the main torus roof surface. In order to remain tilted in cross section, the triangular trusses depend on the torsional restraint of the continuous arches. In order to achieve the crisp contour lines of the welded triangular pipe truss girder, the working points of the triangular truss were placed offset from the face of the triangular box yokes that support the continuous arches instead of at the center of the box yokes. The triangular trusses were designed to resist the moments created by the offset working points.

The continuous arch end spans vary in length from the circumferential triangular truss to the front north wall because the planar vertical north wall truncates the arch end span at ever decreasing spans. As the spans decrease the end reaction of the continuous arches reverses from compression to tension. Then, finally, at the last arch the uplift force due to the small end "back up" span would have been too large for the foundation to resist and the joint had to be released vertically. At the last end column of the end arch there is a unique vertical spherical bushing that provides lateral support for the end column while allowing vertical movement and rotation of the last arch truss end span.

Next to the main arch space the next most dramatic design element is the sloped end walls. Enclosing the main ticket lobby space at each end are the two sloped end walls. The end walls start out straight and then slope outwards to a maximum of 18' beyond their vertical plane. The proportion of vertical face to sloped face is constantly changing as the wall is kinked along a diagonal line along its elevation. The framework that creates this kinked sloped end wall is a series of boomerang trusses reaching a height of 50'. The boomerang trusses also use the "pi" shaped box section as its main members, which again greatly simplifies the fabrication.

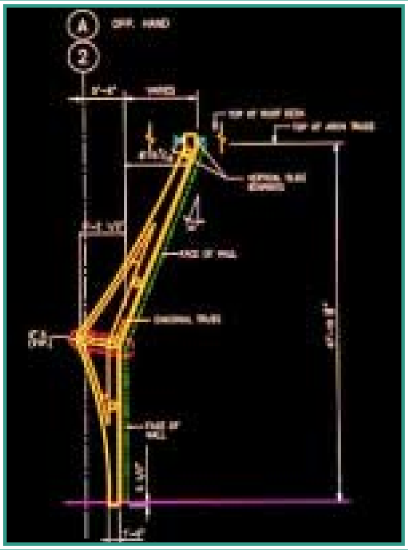
For the end wall framing to be exposed under the fire code the end wall could not support the roof. As a result, there had to be vertical expansion joints in the roof to support the top of the walls laterally but not impose loads vertically. The roof had to be self-supporting and cantilever 35' over the end walls to meet the fire code. Since the end walls leaned out, they had to be laterally braced at the top and bottom of the boomerang trusses. At the bottom of the boomerang trusses the departure level floor acts as the lateral brace and at the top of the boomerang trusses the roof structure acts as the lateral brace. The roof in turn has horizontal "X" bracing to resist the lateral forces created by the sloped end walls gravity loads as well as to resist wind and seismic forces.

The roof horizontal "X" bracing also played a substantial role in making the 40' cantilever front canopy possible. The 40' cantilever canopy has no horizontal back up span but instead is moment connected to the columns. The canopy is attached to freestanding 36" deep wide flange columns which in some cases free span up to 60' from the arrivals level to the roof. These columns depend on the roof framing to hold back these columns laterally. The bracing of the top of the front wall was complicated by the fact that the front wall columns were perpendicular to the front wall whereas the main roof bracing members (the roof arches) are on a radial grid and come into the top of the column at constantly varying angles in plan. This geometry requires that forces not only be resisted along the arch's radial lines, but also requires in plane forces in the front wall to be created to balance the non-coincident lateral force of the vertical columns located at an angle to the roof's radial grid. The front wall bracing resists these secondary forces. The lateral restraint of the roof framing required to restrain the front canopy via the front wall columns was provided by the roof horizontal cross bracing. The roof cross bracing in turn spanned up to 160' horizontally to side wall bracing that ultimately restrained the front canopy and north-south wind and seismic loads.

The front canopy also utilized a similar "pi" shaped cross-section as the leaping roof arches. The purlins of the canopy consist of perimeter pipes and interior purlins consisting of a composite of a pipe and a structural tee. As a result, the inner purlins are much stiffer than the perimeter purlins. This factor made it possible to make the purlins span the end bays of the canopy which are 50% longer than the typical canopy bay using the same size purlins. A midspan distribution rib transfers loads from the exterior pipe purlins to the inner stiffer composite purlins.

Other elements of the building take their lead from the leaping arches. Most notable of these design elements is the concourse skylight frame. The skylight uses a half-arch cross-section to span the concourse skylight opening. The half-arch profile creates a north light skylight affect. Spanning the longitudinal direction is a series of composite purlins made up of pipes welded together with a structural tee. This composite member spans the 37' between the half-arch girders. The half arch girders of the concourse skylights have relatively small spans of under 25' and therefore are not box girders but instead single web plate girders.

Nothing more epitomizes the new millennium design of Terminal One than its interior island ticket counter offices called the ATO. Starting with the ATO's main axis being perpendicular to the front wall these island ticket counter offices have an international orientation allowing thru pedestrian circulation to the main gate's concourse portal from the front wall and result in a full vista of the terminal. Terminal One ticket offices are unlike any other ticket office in an airport terminal in America. The ticket offices



Project Team

Structural Engineers:
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Architects:
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Construction Manager:
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Fabricator:
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- Midwest Steel, Inc.

have a hi-tech design that is keynoted by the propeller-like canopy ribs that cantilever above and over the ticket counters. These canopies have a hinge bushing at their support to enhance the image of a propeller axle. With the hinge comes the need for a cable stay to create the cantilever canopy. Sensitive computer monitors are supported off the stayed cantilever canopy. Adding to the complexity of design were the baggage conveyors below the ticket office that greatly restrict the headroom available to the arrivals level. To overcome this headroom restriction, the floor directly below the ticket office is hung from ticket office roof's framing to allow reduced beam depths around the ticket offices and thus to provide the maximum clearance for the baggage conveyors below.

Lateral Resistance

One of the keys to the overall economy and achieving the unique structural systems of Terminal One is the structural lateral resistance systems of the building. New York City is considered a moderate seismic area and provisions for seismic resistance were built in the lateral structural system as required by the building code.

The lateral resistance structural system developed used in the north south direction consisted of bracing between the arrivals and departure levels and moment frames above the departure level. The departure level's slab was concrete on metal deck and acted as a redistribution diaphragm between the moment frames above and the bracing below the departure level. The vertical bracing below the departure level and had to be located in the "back of the house areas" which were available in the lower arrivals level such as mechanical rooms. Key to the building's success was incorporating the bracing in the public baggage areas. The bracing in the public baggage area paralleled the sloped baggage conveyors in these areas and as such the bracing became almost undetectable from the baggage conveyor.

Moment frames were used for lateral resistance above the departure level floor for the main terminal. The moment frames were placed in the multilevel framing that housed the gates at the departure level and the airlines lounges and food court at the mezzanine level in the main terminal. The high roof over the ticket lobby depends on this framing for its lateral resistance.

Vertical bracing in the north front wall and ticket lobby demarcation walls provide lateral resistance in the east-west direction (circumferential) direction in the main terminal above the departure level. This east west bracing is augmented by the moment frames in the multilevel gate and lounge areas above the departure level. Below the departure level similar to the north-south direction, bracing alone provides the lateral resistance.

The main south concourse finger gate area has moment frames in the short direction. In the long direction bracing from the arrivals to the departure level and moment frames above the departure level provide the lateral resistance.

Terminal One is an example of how the limitations of economic construction and fabrication provide the opportunity to create a new structural aesthetic. The aesthetic of the contoured plate girder represents the economic flexibility of structural steel fabrication. Enhancing the overall composition is the juxtaposition of the radial plan grid with the rectilinear grid of the front wall. The result is a sense of perspective and progression that is rarely achieved in airport terminal design. Terminal One shows how a balance of standardization and geometry can create a unique and exciting structural aesthetic when combined with the advantages of structural steel fabrication.

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