



Figure 1: An Airbus A380-800

KLIA'S NEW A380 HANGAR

A Retrospective by Ir. Ahmad Razef bin Ab Rahman, P.Eng, MIEM, MACEM, Ir. Wong Wai Wah, P.Eng, MIEM, MACEM, and Ir. Azmi Merican, MIEM

In 2006, MAS built a new multipurpose hangar to accommodate the maintenance of Airbus A380-800 aircraft. THE INGENIEUR looks back at the building of this structure, from the design of the concept to its construction.

The Project Background

In December 2003, Penerbangan Malaysia Berhad (PMB), the parent company of Malaysia Airlines System Berhad (MAS), signed a contract with Airbus SAS for the purchase of six Airbus A380-800 passenger aircraft. This aircraft is a double-decker super-jumbo, able to seat 525 people in a typical three-class configuration or up to 853 people in an all-economy class configuration. It is the largest passenger aircraft in the world. See Figure 1 showing a photograph of an Airbus A380-800.

With the expectation to receive the super jumbo and the future expansion of aircraft maintenance capabilities, MAS had decided to build one new multipurpose heavy maintenance hangar located within MAS Complex at Kuala Lumpur International Airport (KLIA).

The Purpose-Built Hangar

The hangar, equipped with special equipment was the first purpose-built hangar in Southeast Asia for the maintenance of the Airbus A380. The hangar covers a total footprint of 23,215 square metres. It took a total of 24 months to build. See Figure 2 for a photograph of the completed hangar. The 230 m clear span entrance was believed to be the world's longest single span hangar at that time.

The established hangar dimensions are summarized in Table 1 below:

Table 1: The hangar dimensions

LENGTH OF ENTRANCE	230 M (CLEAR DISTANCE)
WIDTH	100 M (CLEAR DISTANCE)
MAXIMUM ROOF HEIGHT	42 M ABOVE FINISH FLOOR LEVEL (FFL)
HEAD ROOM IN HANGAR	32 M ABOVE FFL
BUILDING AREA	23,215 M2
HANGAR FINISH FLOOR LEVEL (FFL)	+17.500 M ABOVE MEAN SEA LEVEL (MSL)



Figure 2: Photograph of the completed hangar

The Basic Design Concept

A design-and-build project, MAS had engaged a local engineering consultant firm as the Basic Designer in the conceptual planning stage and later, as the Project Management Consultant during the construction stage. Through the tendering process, a consortium of contractors (consisting of a local contractor and two international contractors) had been awarded as the Design and Build Contractor for the construction of the Project.

The Hangar Complex comprised the all steel Hangar superstructure, a two-storey reinforced concrete Hangar Shop, a single storey reinforced concrete Amenity Building, a single storey Power Plant, a two storey Utility Building, a Canteen, related M&E services and infrastructure such as roads, drainage and others. However, this retrospective is focused only on the conceptual design and the implementation for the construction of the Hangar proper. The designer and the Client's (MAS) project team worked hand-in-hand in the emulation of the Client's ambition into a workable basic design concept for the Project, in compliance with the prevailing design standards, Uniform Building By-Laws, the aviation industry's and the local authority's rules and regulations.

SPACIOUS HANGAR

The Client required that the hangar size to be optimized within the given footprint and remain flexible for maintenance of Airbus A380 aircraft with other types of aircraft at the same time. Three parking bays in the hangar namely Line 1, Line 2 and Line 3 were planned. When in parked position the minimum safe distances allowed between two aircraft was 7 m and between a parked aircraft and the wall was 10 m. See Table 2 showing aircraft types and sizes to be parked in the hangar and between a parked aircraft and the wall was 10 m. See Table 2 showing aircraft types and sizes to be parked in the hangar.

Table 2: Aircrafts types and sizes to be parked in the hangar

AIRCRAFT TYPES	LENGTH (NOSE TO TAIL), M	WIDTH (WING SPAN), M	HEIGHT (TAIL HEIGHT), M
AIRBUS A380-900	79.40	79.75	24.19
AIRBUS A330-300	63.69	60.30	17.18
BOEING B777-200	63.73	60.95	18.45
BOEING B747-400	70.67	64.94	19.40
BOEING B737-800	39.50	34.30	12.50

To achieve that, the entire 200m x 100m internal hangar floor was designed as an open space, free of columns, plinths, open-pits and floor mounted equipment. Five aircraft parking options were found to be possible for multiple aircraft maintenance in the hangar. For instance the hangar could accommodate two Airbus A380-800s and one Boeing B737-800 in one of the parking options. See Figure 3 showing Parking Option 1.

SUSPENDED TELEPLATFORMS AND CRANES

Special equipment for Airbus A380 maintenance (suspended from the roof as described below) were considered in the concept design:

- a) Two sets of big aerial telescopic work platform (i.e. teleplatform) attached to double girder bridge cranes with 750 kg slewing jib, able to access 95% of roof areas i.e. covering Line 1, Line 2 and Line 3 and allow comfortable working space for maintenance of all aircraft types in the five parking options.

- b) Two sets double girder bridge crane with 15-ton hoists.
- c) One set double girder bridge crane with 5-ton hoist.
- d) One set parking spur in the roof confines for parking an idle teleplatform.

SUSPENDED FUTURE DOCKING SYSTEM

Another piece of heavy equipment suspended from the roof would be the future docking system. It would consist of one complete set of Aircraft Docking System (i.e.100 ton Heavy Maintenance Docks) to serve A380-800/900 parked Nose-in in Line 3.

It comprises the fuselage, nose and tail dockings together with the associated bridges and runway beams. While not in use, it would be stowed away in the roof, to allow light maintenance to be performed on other aircraft parked in the Nose-in position. See Conceptual Future Docking System in Figure 4.

Figure 3: Parking Option With 2 Airbus A380-800 and 1 Boeing B737-800

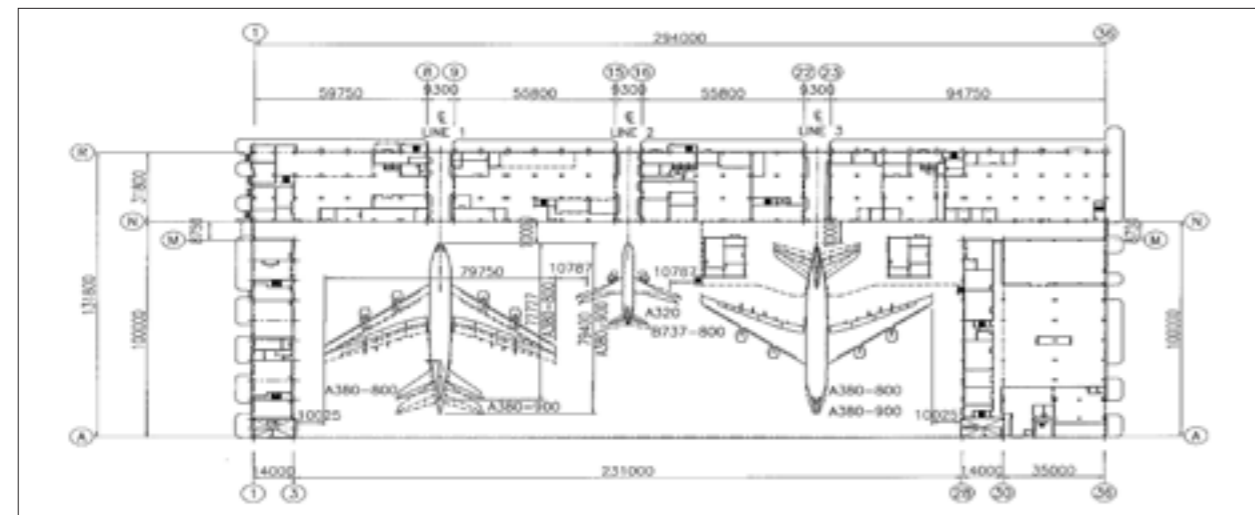


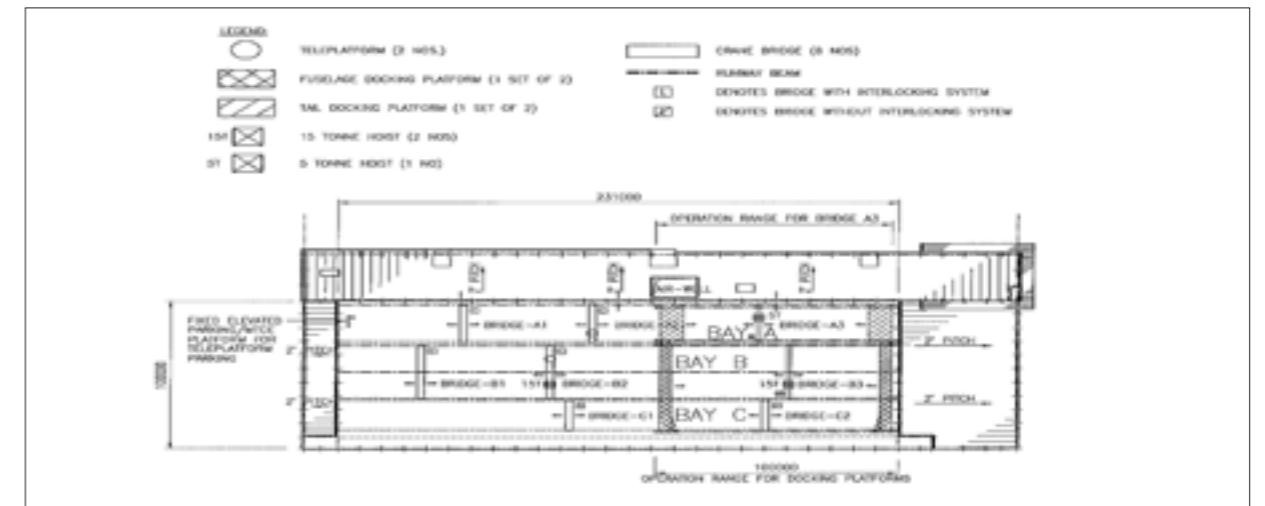
Figure 4: Conceptual future docking system suspended from roof

THE COMPLICATED REQUIREMENT FOR CRANE BRIDGE RUNWAYS SUSPENDED FROM THE ROOF

It was required that:

- a) Three sets teleplatform runway beams to be made available, each to cover 1/3 of the roof area i.e. at back of hangar (Bay A), middle of hangar (Bay B) and the front of hangar (Bay C). The teleplatforms besides running on its own runway beams, shall be able to cross to the next runway beams at any point using a special device to interlock with the adjacent runway beams (i.e. enabling them to operate in all bays).
- b) Two sets of crane runway beams be made available for the two 15-ton cranes, one in Bay A and the other in Bay C of the roof area and covering Line 1, Line 2 and Line 3 parking bays.
- c) One set of crane runway beams be installed for the 5-ton crane covering Bay B but confined within Line 3 parking bay only.

Figure 5: Layout of the Various crane bridge runways under the hangar roof



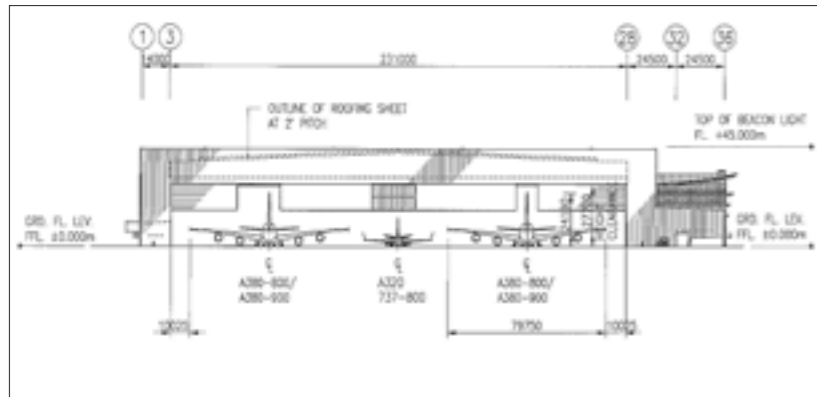
It was a complex exercise to arrange the runway beams in the most efficient manner for the equipment to cater for the various combinations of multiple aircraft as well as the five parking options. It was also a painstaking coordination exercise to avoid clashes with other installations such as the high bay lighting, fire fighting heat and linear detectors, foam sprinkler piping and the catwalk in the way of the various cranes. See Figure 5.

GROUND SERVICE PITS AND LANDING GEAR SYSTEM

Ground service pits with heavy duty cover houses the 400 Hz power units, pre-conditioned air, compressed air supply and others below the parking apron. The utilities are drawn out of the pits for use during aircraft maintenance.

The Landing Gear System consists of the Fuselage and the Nose Landing Gear Platforms. The platforms are leveled with the parking apron and can move down within the concrete pits, providing a simple maintenance process for removing, testing or replacing the aircraft landing gears.

Figure 6: Front elevation of the hangar



While the landing gear is being serviced or replaced it also allows other maintenance crew to work on the aircraft at the same time.

All the drive system components and electrical control units are mounted at the base of the concrete pits.

THE HEIGHT LIMITATION

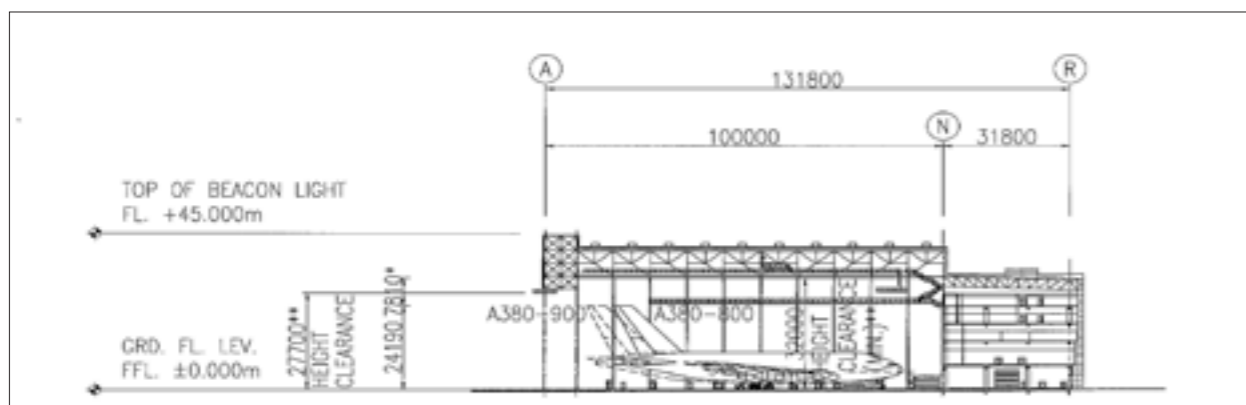
The roof had to be tall enough to accommodate the doubled-decked Airbus A380 but at the same time the DCA's (Department of Civil Aviation) height limitation must not be exceeded.

There were two height limitation criteria imposed by DCA based on ICAO's (International Civil Aviation Organization) Annex 14-Aerodromes for any development within the KLIA zone:

CRITERION 1

The peak of structures shall be below the flight path envelope of 1:7 measured from a distance of 150 m from the centerline of the nearest runway (in this case Runway 2 was nearest) and climbing with the gradient outward. The height limit for the Hangar was found to be at level +73.000 m MSL (above the Mean Sea Level) for it was at 530 m away from the start of the flight path envelope.

Figure 7: Cross section of the hangar



CRITERION 2

The peak of structures within 4 km radius from the KLIA Control Tower can not be higher than 45 m above the minimum Threshold Level which was +14.500 m MSL measured at the end of Runway 2. Therefore the height limit was +59.500 m MSL (i.e. 45 + 14.500 = 59.500)

Criterion 2 was more stringent; therefore the hangar roof shall not exceed +59.500 m MSL or 42 m above the Hangar finish floor level of +17.500 m MSL. It was also required that the headroom under the entrance main truss could not be lower than 27.190 m to clear the Airbus A380's rudder height of 24.190 m and the headroom inside the hangar under the sub-trusses could not be lower than 32.000 m to allow the teleplatforms to pass above the rudder. As a consequence, the trusses depths were constrained within the maximum height limitation by DCA and the minimum headroom requirement for the Airbus A380 rudder. It turned out the main truss depth was limited to 14.81 m and the sub-trusses depth varied from 10m at the ridge reducing to 5 m at the eaves due to the 2° pitched roof. See Figures 6 and 7.

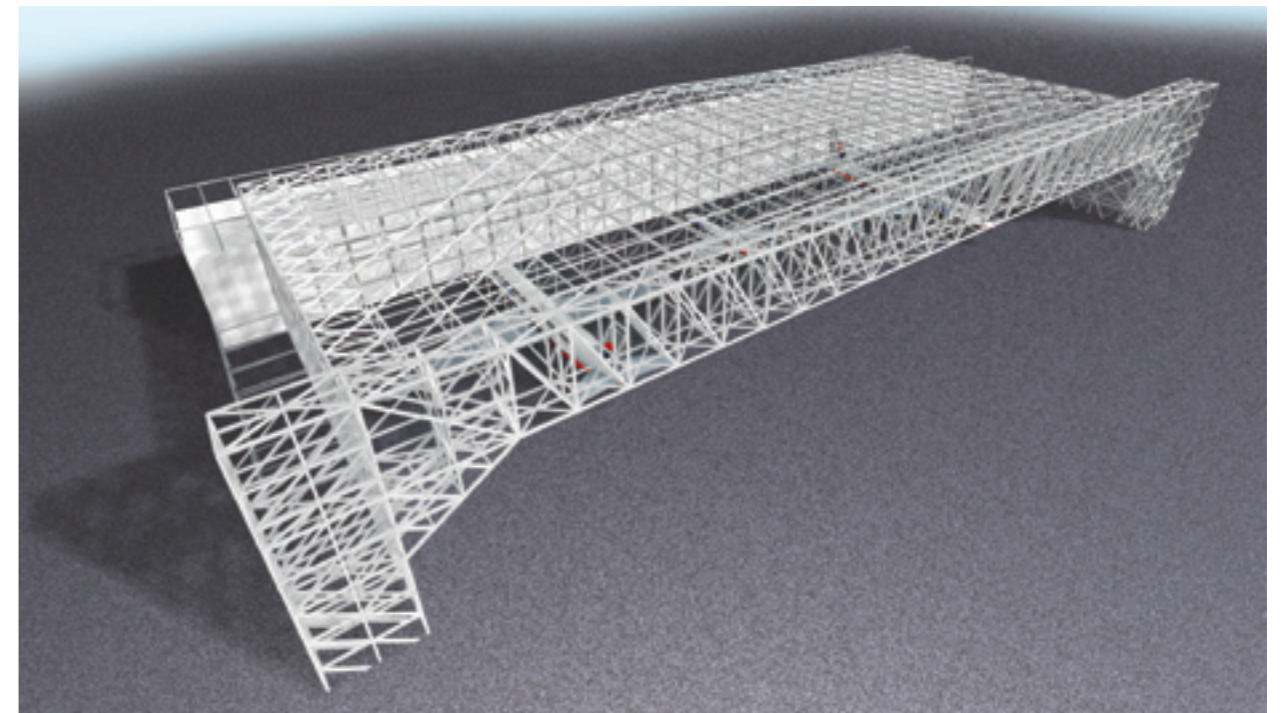


Figure 8: The bird's eye view of the 3D model of the hangar structure

The Concept Modeling and Evaluation

The hangar superstructure had been modelled to consist of two main columns – a 230 m span gate-type main truss (the entrance) and 100 m span sub-trusses. The sub-trusses were supported by the main truss on one end and on the workshop columns at the other end. The sub-trusses in turn carried the purlins for steel roofing sheets attachment, the docking, the crane systems and others. Top and bottom cord bracings together with vertical bracings were provided for the lateral stability of the hangar structure. See the hangar structure 3D model in Figure 8.

In general, the steel design and construction guidelines by British, Malaysian, American, and Japanese authorities, as well as manufacturer's standards and practices on structural use of steelwork in building were adopted. The concept had been rigorously evaluated based on the standards and practices for every case affecting the hangar superstructure's integrity. Structurally all the above conditions were very critical because it has a very large column-free span, heavy roof loadings and limited trusses depths for design.

Preliminary evaluation of the concept involved:

THE MAIN TRUSS SUPPORTING THE PERPENDICULAR ARRANGEMENT OF SUB-TRUSSES

The gate-type main truss was selected as it can span the extremely large clear span of 230 m with various loads. At an early stage, the sub-trusses' arrangement had been explored by spanning 230 m paralleled with the main truss but it was found to be inefficient and uneconomical.

The perpendicularly laid sub-trusses with respect to the main truss were adopted for the basic design purpose. See the hangar model in Figure 9.

The structure was checked for the worst combinations of loads with allowances being made for dynamic loads combined in the most unfavourable conditions for each structural member.

Being a large span structure with height limitations, control of deflection was of the utmost importance. At an early stage, numerous investigations on trusses geometry were done to satisfy the deflection, stress and torsion requirements.

Originally the main truss was modelled using the single-box concept. After preliminary structural analysis however, the single-box concept was found to be not suitable. It had to be built from fabricated plate sections because the member sizes required were out of the market range for hot rolled steel sections. Therefore single-box main truss was not favoured because the utilization of fabricated plate sections would incur welding quality problems, longer fabrication times and high costs.

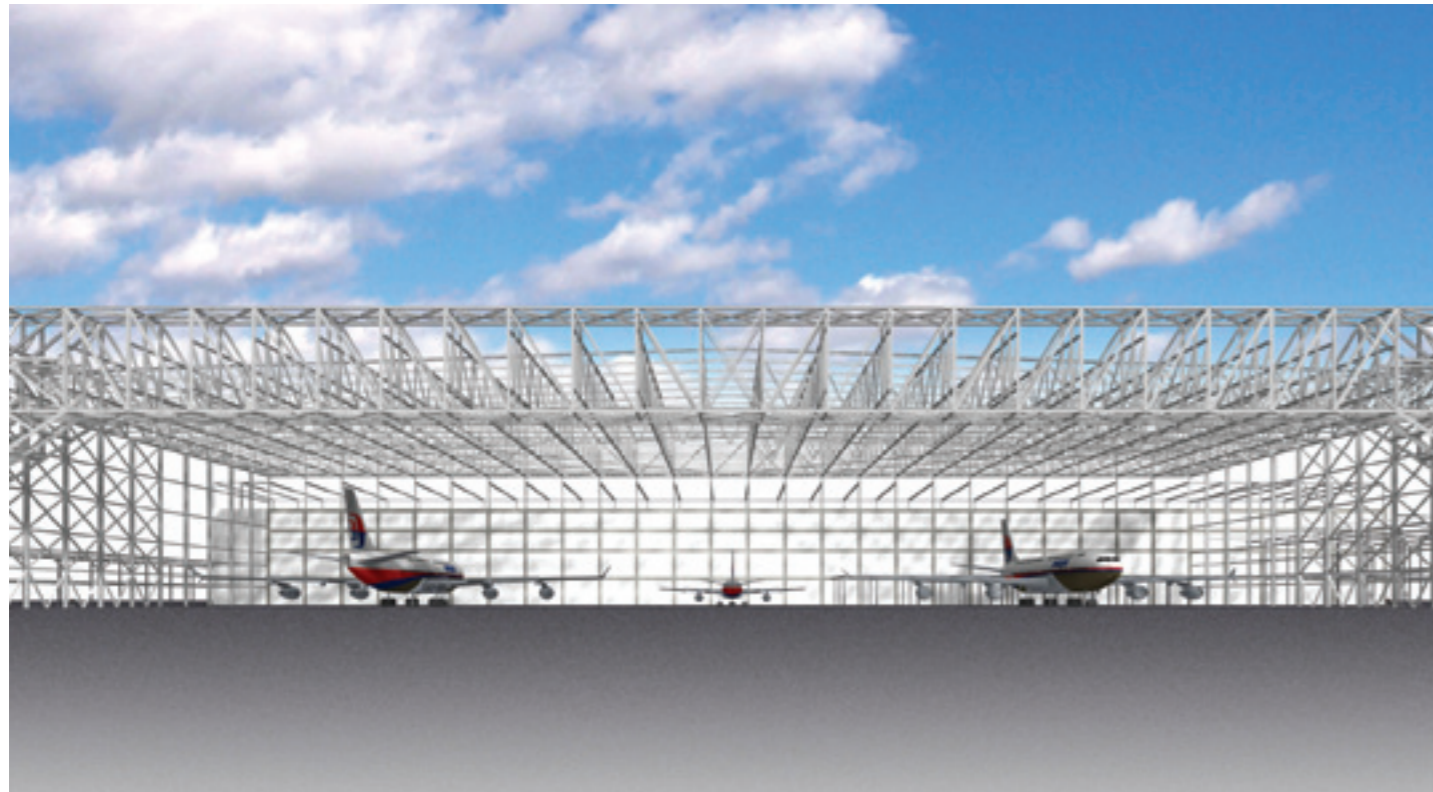
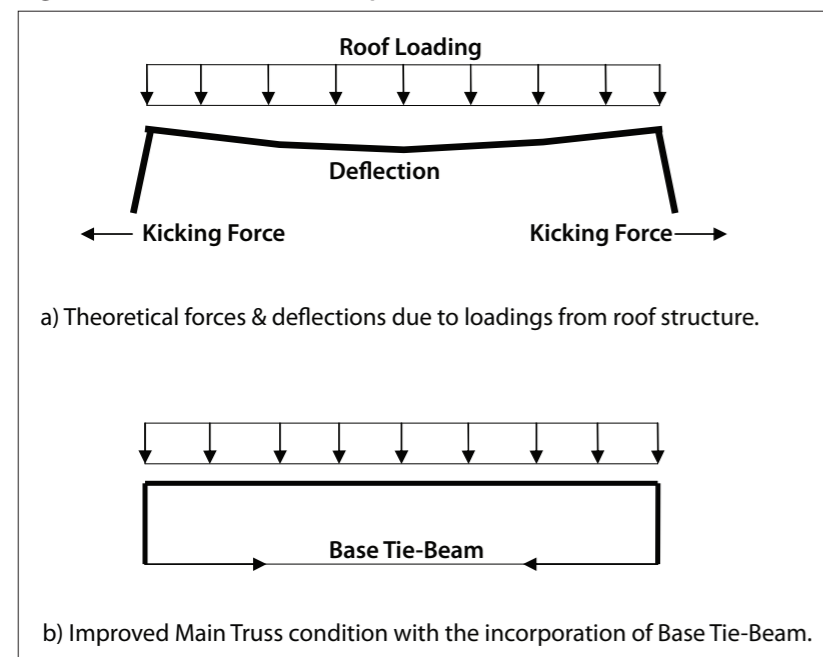


Figure 9: The front view of the 3D model of the hangar structure

Subsequently it was re-modelled as a twin-box compound truss and it was found to be efficient and most appropriate as compared to the single-box truss. In terms of materials, Grade 50B high tensile hot rolled sections were also readily available from the market. Therefore the twin-box gate truss was incorporated in the tender drawings. The use of Grade 50B hot rolled steel sections also helped to reduce weight and save cost.

Figure 10: Base Tie-Beam concept



THE BASE TIE-BEAM

The two main columns are of all-steel compound-box frame supporting the main truss. The cast-in-situ concrete piles foundation was deemed to be the most suitable for big point loads transferred by the columns.

There would be a big lateral outward thrust induced at the base of the columns. With reference to the designer's own experience in the detailed design of Hangar 05 situated next to the proposed structure, a base tie-beam has to be incorporated for the integrity of the whole hangar superstructure. See conceptual model in Figure 10.

The lateral restraint can be in the form of reinforced concrete tie, structural steel tie or pre-stressed concrete tie. The incorporation of the tie was vital to control or reduce the lateral deflection of piles head and the supporting columns. Without it, the piles head, the supporting columns and the main gate truss would be subject to excessive deflections and overstressing.

DEFLECTION CONTROL

Individual members and the structure as a whole were checked against deflections due to self-weight, superimposed dead loads, wind loads, and suspended equipment dynamic loads. Cambers to roof were made to nullify the deflection due to the dead loads for level installation. The prospective contractor had to take this into account and show in the shop drawings the cambered trusses so that each member shall be cut correctly to the cambered length in the actual fabrication.

Again, the horizontal and vertical deflections of individual structure element were checked due to operation of the docking system, teleplatforms and cranes acting on the bottom chords and kept within the specified limits as required by the supplier to ensure satisfactory operations.

Also the deflection after the installation of equipment shall be controlled such that:

- The minimum clear heights are achieved
- The runway beams can be easily installed to level
- The performance of the equipment is not adversely affected
- The interlock-bridging for teleplatforms to cross to another runway beams is not affected.

In addition the deflections shall be within the code stipulated limits.

VIBRATION CONTROL

The structure as a whole was checked against vibrations due to dynamic loads arising from wind and operation of equipment. Dynamic analysis was carried out and it was found that the fundamental natural frequency of the structure was less than 1 Hz, hence the dynamic structural behaviour did not govern the design.

TORSION CONTROL

Major torsion would be induced in the main truss due to 50% of the roof loads being transferred eccentrically to its major axis. During the concept development it had been noted that the compound twin-box main truss was better than the single-box main truss for resisting big torsional stresses. Also the prospective contractor was cautioned to take into account the torsion in the main truss and distortion in the structures during erection. Pre-assembling the main truss and the sub-trusses on the ground was desirable. The prospective contractor was advised to study the erection method and sequence so as to keep the twin-box main truss always in upright position to avoid misfit to the columns and to minimize distortion of the roof structure during the lifting into position.

Proven Concept

The concept was a deflection driven design due to the large span, heavy loads and restricted superstructure depths. The basic design concept as deliberated above had been incorporated in the Needs Statement, Tender Drawings and the Specifications for tendering.

Concept from the basic design formed the base bid. Pre-qualified local and international bidders were invited to participate in the tender and they were encouraged to submit their own alternative bid if a better structural solution can be suggested, compared to the base bid.

Alternative bids were submitted but they were found to be structurally inefficient or more costly than the base bid. The original basic design concept was therefore proven to be a superior option technically and financially because the contractor had adopted it for their detailed design and construction as compared to their option.

Detailed Design Audit

The designer had closely monitored and carried out a design audit during the detailed design to ensure the conformance in the required concept, Needs Statement and Specifications.

To cite some points among others, the following had been deliberated in the detailed design audit:

PLACING OF THE CRANE RUNWAY BEAMS

The designer and MAS Project Team had deliberated on the requirements during the concept development and detailed in the tender drawings. The designer had further assisted the contractor to plan the final positioning of the crane runway beams, due to their complex nature. Due to the various moving loads the contractor was requested to check the individual members' deflections as well as global structural deflections to satisfy the equipment suppliers' and the interlocking bridge's operational tolerance limitation.



Figure 11: Hangar roof structure lifting in progress

BASE TIE-BEAM

Initially, the Contractor proposed no restraint to the column bases by allowing the columns base to move freely to attain the equilibrium. The assumption was not acceptable because it changed the member stresses and conditions of the original design boundary parameters.

The designer had insisted that base tie-beam was important for the whole superstructure integrity. The designer was of the opinion that once the columns base moved, it would laterally stress the piles head and subsequently would break the piles. It would be unacceptable when the vertical piles supporting the main gate structure are stressed excessively for it would endanger the entire hangar superstructure. A lateral thrust of 2400 tons was the expected value and eventually the contractor had introduced post-tensioned cables in the foundation beams, tying the columns base to resist the thrust, thus resolving the potential piles failure problem by the large amount of lateral thrust.

Construction

Stresses, deflections and torsion control was managed by advising the contractor to pre- assemble the structures i.e. the main truss together with the sub-trusses on the ground and lifted-up from the supports on which the roof was erected to the final height. See Figure 13.

The method of lifting of the whole roof truss was deliberated with the contractor prior the lifting operation. The designer had highlighted to the contractor on the torsional deflection of the main truss during lifting because 50% of the total weights was eccentrically carried by the main truss structure. Hence the other ends of the secondary trusses were lifted up higher from the finish position during lifting to counter the torsional distortion so that the main truss was always in the up-right position during lifting and when bolting it to the columns. After the main truss was installed in the finished position, the ends of the secondary trusses were then lowered down and fixed in their final positions.

All roofing sheets were stacked on the trusses and crane beams were loosely bolted to the bottom chords to allow

slight movement during lifting. They were fixed properly only after the lifting operation was completed and the superstructure was finally completely installed. As a result of careful analysis and sound judgment, the erection and lifting operation had been smoothly executed without any problem.

Conclusion

The new A380 Hangar has been successfully installed. Summarized below are the salient points that had been deliberated in the concept development for the New Hangar:

Table 3: Concept Development Summary

ITEM	DESCRIPTION	REMARK
A	PURPOSED BUILT HANGAR	• The first hangar being built in Asia for light and heavy maintenance of world latest super jumbo A380.
B	BIG SPAN GATE TYPE MAIN TRUSS AND PERPENDICULARLY LAID SUB-TRUSSES	• 230 m column-free span hangar entrance for multiple aircrafts parking and flexible multiple aircraft maintenance. • More efficient and economical structural arrangement. • Utilities and Landing Gear System installed in special pits under the floor for space optimization.
C	TWIN-BOX MAIN TRUSS	• Utilize twin-box girder to resist heavy torsion in the main truss. • Warrant the use of hot rolled sections instead of fabricated plate sections. • Save time and cost as compared to using fabricated plate sections in single-box main truss.
D	SHALLOW TRUSS DEPTHS	• Height limitation by DCA/ICAO. • Requires stringent deflection, vibration check and control.
E	HEAVY LOAD ON THE TRUSSES	• 50% roof load carried by the main truss and heavy special equipments hanged from the sub-trusses. • Special equipment suspended from roof such as the Docking System, Teleplatform and cranes. • Use of Grade 50B High tensile steel to reduce weight.
F	COLUMNS BASE OUTWARD LATERAL FORCE	• Introduction of tie-beam to counter the big kicking lateral forces at the main gate columns base.
G	PRE-ASSEMBLED AT GROUND LEVEL	• Pre-assembling of main truss and sub-trusses at ground level to minimize distortion effect and misfit during erection. • Cambering the trusses to cancel the sagging due to dead loads.

In anticipation for the Airbus A380-800 delivery, MAS had accomplished its readiness for:

- a) Maintenance for super jumbos A380-800/900.

- b) A multipurpose flexible usage hangar for other aircrafts.
- c) A sophisticated hangar, having the services and landing gear facilities in pits under the floor and docking system hanged from the roof and parked within the roof structure.
- d) Maximum space utilization by having large column free space, planned parking options and planned overhead docking system, teleplatforms and cranes to accommodate multiple aircraft at any one time.

The task of combining all the above concepts and designs on the drawing table was done by the designer, working in tandem with input from MAS's resourceful Project Team. In addition, the designer also made use of past experience in the detailed design of MAS's Light Maintenance Hangar 03 in Subang and Hangar 05 in KLIA.

With smooth progress, the new hangar was finally built to completion as per the original basic plan laid out in the Needs Statement, tender drawings and the specifications because all factors had been closely deliberated in a team effort by all parties from the inception of basic design until construction completion.

The authors are grateful to MAS for allowing this documented work experience to be published for the benefits of the greater engineering fraternity.