Summary Report for a Structural Design of a Maintenance Hangar for a C-27J Airfield Training Facility

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As part of the UNSW Canberra integrated design team, this report details the methodology, assumptions and justification for the structural design of a maintenance hangar for a proposed C-27J Airfield Training Facility in a remote location. As part of a team of three engineers, this report details the process and justifies why particular methods and sections were adopted to design the maintenance hangar. These designs are developed due to the recent ADF procurement of the Alenia C-27J Spartan aircraft as a replacement of the Caribou A4 DHC-4 capability in 2016. This aircraft provides the logistic support required for air mobility through airborne operations within the regional responsibilities of Australia with a short (580m) runway requirement. The design of the hangar has been integrated with project management of a runway and terminal design conducted by Ben Whyte and Daniel Parkinson. ADF policy, Australian Standards, Building Code of Australia (BCA), and where there is a lack of Australian policy, United States Air Force documentation has been used throughout this project.

1 Lieutenant, School of Engineering & Information Technology. ZEIT4500.
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I. Nomenclature

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<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADF</td>
<td>Australian Defence Force</td>
</tr>
<tr>
<td>APOD</td>
<td>Air Point of Disembarkation</td>
</tr>
<tr>
<td>ARA</td>
<td>Australian Regular Army</td>
</tr>
<tr>
<td>AS</td>
<td>Australian Standard</td>
</tr>
<tr>
<td>ASI</td>
<td>Australian Steel Institute</td>
</tr>
<tr>
<td>RAAF</td>
<td>Royal Australian Air Force</td>
</tr>
<tr>
<td>RAE</td>
<td>Royal Australian Engineers</td>
</tr>
<tr>
<td>USACE</td>
<td>United States Army Corps of Engineers</td>
</tr>
<tr>
<td>USAF</td>
<td>United States Air Force</td>
</tr>
</tbody>
</table>

II. Acknowledgements

The conduct of this project was supervised by Dr Amar Khennane. In addition to Dr Khennane, assistance was sought from current Royal Australian Engineer and Royal Australian Airforce Airfield Engineers, academics within UNSW, professional practicing engineers, and numerous engineering firms. The following list details these personnel:

<table>
<thead>
<tr>
<th>Category</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supervisor</td>
<td>Dr Amar Khennane</td>
</tr>
<tr>
<td>UNSW Academic Staff</td>
<td>A/pro Obada Kayali</td>
</tr>
<tr>
<td>A/pro Robert Lo</td>
<td>Dr Rajah Ghanandran</td>
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<tr>
<td>Dr Mahmud Ashraf</td>
<td>Dr Safat Al-Deen</td>
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<tr>
<td>Professional Practicing Engineers</td>
<td>Ian Hooley</td>
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<td>Australian Defence Force Engineers</td>
<td>SQNLDR Rowan Paice</td>
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<td>FLGOFF Chris Kluft</td>
<td>FLGOFF Samuel Bartlett</td>
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<td>Engineering Firms/Companies</td>
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<td>AutoDESK</td>
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<td></td>
<td>Cordell</td>
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<tr>
<td></td>
<td>Cardno Bowler</td>
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I. Introduction

The design of a maintenance hangar provided numerous challenges to consolidate the objectives of a BE Civil from UNSW Canberra. This ranged from the development of a design scope, architectural and the Building Code of Australia (BCA) requirements, the type of structure to be designed, the analysis to be conducted, the loads acting on the structure, and member selections. Further to this, it presented the opportunity to research the most applicable programming to conduct the analysis required, be that for structural analysis or for project management. It further provided the opportunity to consolidate structural design using structural steel, concrete and geotechnical data. Finally, it provided the opportunity to consolidate knowledge of project management for a large project based on current ADF developments. With this in mind, the following report details the project scope, the methodology and justification for the design conducted. It presents the final designs to be constructed and a summary of the project management components.

A. Scenario Description

In response to the retirement of the Royal Australian Air Force (RAAF) Caribou A4 DHC-4 in 2009, the ADF has commenced the acquisition of the Alenia C-27J Spartan aircraft through the United States Air Force (USAF). [52] This aircraft provides the ADF with the capability to provide air mobility through air logistic support and airborne operations within the regional responsibilities of Australia. With this acquisition, there is a requirement to develop and maintain training to maintain proficiency of its use in remote locations.

The design of the airfield stems from an Air Point of Disembarkation (APOD), Amberley designed in 2011 [1]. This was a design to conduct training for the establishment, protection and operation from an airfield, in particular an evacuation operation. All the facilities were designed to be non-habitable with a grassed runway. This project utilized the location of the APOD to design structural concepts for an airfield used solely for a C-27J Spartan. The facility will serve to support short duration training of evacuation and battlefield airlift take off and landings in remote areas.

B. Scope of works

The structural designs to be produced from the team included the following:

- airfield hangar for permanent storage of the C-27J (Daniel Parkinson),
- maintenance hangar for a single C-27J and supporting equipment (Scott Atkinson),
- C-27J airstrip, apron and pavement access to the facility (Ben Whyte).

The project management included an integrated critical path diagram and an individual bill of materials.

C. Restrictions

The project did not include the design of services such as electrical, mechanical, drainage to the main system, water, sanitary plumbing, provision and installation of a telephone system, data network, lightning protection, electromagnetic protection, floor ducts, risers, cable trays, cable entry pipes and pits for all services, and security. Fire resistance levels were considered in the overarching design but were not specifically designed. [15] The primary responsibility of the engineer is the design for actions. The design of fire resistance is generally conducted by an architect. [55] Further, the specific placement and product of fire protection was not considered, only the impact on the layout regarding entrances, exits and access.

D. Integrated components

The conduct of this project involved the consolidation of fundamental theoretical concepts in a current design scenario for ADF personnel. Fundamental concepts from structural steel design, concrete structures, geotechnical engineering, and project management were required. For this project, Daniel Parkinson, myself and Ben Whyte integrated components. These included the scenario development, the foundation data and implementation of recommendations from the Cardno Bowler report [37], the design methodology including the type of analysis, connection design methods, slab design and footing design, the overall project costs and the critical path diagram for the project.

E. Project difficulties

The conduct of this project presented numerous difficulties and delays. These included the scenario development and the outputs required. Liaising with the personnel mentioned in the acknowledgment took significant time away from the initial components of the design. Obtaining and gaining an understanding of the programming delayed progress, despite foresight to look into these programs months in advance. These programs included Microstran, AutoCAD Structural Detailing and Cordell. Conducting literature reviews of multiple design methods delayed the output of significant steps, in particular the geotechnical components.
III. Aircraft Design Parameters

The Alenia C-27J Spartan specifications used for the design were:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Takeoff Weight</td>
<td>31,800 kg</td>
</tr>
<tr>
<td>Max Landing Weight</td>
<td>30,500 kg (long angle approach), 27,500 kg (steep approach)</td>
</tr>
<tr>
<td>Payload</td>
<td>11,500 kg</td>
</tr>
<tr>
<td>Min Takeoff Distance</td>
<td>580 m</td>
</tr>
<tr>
<td>Min Landing Distance</td>
<td>340 m</td>
</tr>
<tr>
<td>Length</td>
<td>22.7 m</td>
</tr>
<tr>
<td>Wingspan</td>
<td>28.7 m</td>
</tr>
<tr>
<td>Height</td>
<td>9.65 m</td>
</tr>
<tr>
<td>Wing area</td>
<td>82 m$^2$</td>
</tr>
<tr>
<td>Empty weight</td>
<td>17,000 kg</td>
</tr>
</tbody>
</table>

Figure 1. C-27J Design Parameters. [19]

IV. Site Details

A. Location

The proposed location of the airfield is given by Figure 2. This is NE of the current RAAF Base Amberley Airfield. This site was adopted due to the available geotechnical report conducted for the 2011 APOD design. [37] The surrounding RAAF Base Amberley was taken as non-existent for the design of the airfield. This was to replicate the design application to a remote location. This removes the requirement to design for conflicting air traffic flow and considerations for noise in residential areas.

Figure 2. Proposed airfield location

V. Choice of Structure

B. Portal Frame vs Truss

A maintenance hangar requires a large floor area of 1000m$^2$ for the conduct of maintenance on a C-27J aircraft. Portal frames provide large clear floor areas and the potential to include an overhead crane up to 10 tonnes. [2] Further to this, a portal frame is ‘superior in appearance and ease of maintenance, and provides more usable interior space than a ridge-type roof truss shed’. [53] Due to this, a portal frame was adopted for the maintenance hangar. Further to this, the use of a portal frame provides the space required for the tail of the aircraft to enter the hangar. The calculations for this will be detailed in Chapter 2 Sizing of the Maintenance Hangar of the final submission.

C. Design life

The facilities were designed for short term use with a design life of 50 years.

VI. Loading

D. Wind Loads

The airfield was designed to withstand Region B wind loads in accordance with the site location and AS1170.2 Wind Loading [5]. The site is Category 2 with relatively open terrain, well scattered obstructions with a height of 1.5m to 10m. The regional wind speed is $V_{500} = 57$ m/s for ultimate limit state design and $V_{50} = 44$ m/s for serviceability limit state design. All wind pressures were calculated from doors open to the full extent to maximise resistance to uplift force. [5]

There were two main directions of wind creating an outwards uplift of the structure and an inwards pressure on the structure. The critical regions were the second and sixth frame due to maximum wind loading and loading area. Due to this, a single frame was designed for this loading and applied to all the frames. It would be more economical to design the structure for individual frame loadings based on their respective tributary area. Though, to do this would be labour intensive and require significant detailing.
The greatest load combination effects in accordance with AS1170.1 [4] were adopted to determine the maximum uplift force and compressive force on the frame.

E. Snow Actions

The proposed location of the airfield is not in a designated Alpine region. These regions include Tasmania, Northern and Southern Tablelands of NSW. Due to this, snow and ice actions were not considered in this project. [6]

F. Earthquake design

The proposed location of the airfield requires design for earthquake actions. Though, currently Earthquake design is a postgraduate requirement. Due to this, it was not considered in this design.

VII. Type of Analysis

G. 2D vs 3D

The choice of a 2D or 3D analysis was decided to simplify the design process. As each frame is designed with a tributary area with no addition of forces from the other frames, a 2D analysis was preferred.

H. Plastic vs Elastic

The design may have been conducted by one of three methods. This includes a nonlinear (second order) elastic analysis, linear elastic analysis and a plastic analysis. [2] Plastic design is not a readily available design process. Due to this, an elastic analysis was adopted over the plastic design option. A linear elastic analysis was conducted using Microstran. The results of this linear elastic analysis were compared to a second order elastic analysis. For portal frames with a pitch less than 15 degrees, an amplification factor for the columns is usually 1-1.15. [24] The differences in the results that will be detailed in Chapter 10 Second Order effects of the final submission indicate this. As there was minimal amplification of the design moments, the linear analysis was adopted.

VIII. Fly Bracing

Fly bracing is used to increase the rafter and column out of plane capacity. They reduce the out of plane sway that may occur from the wind loading on the structure. Due to this, fly bracing was adopted at large moments. The spacing was determined from AS4100 CL 5.3.2.4. This clause details the spacing required to minimise the amplification moment for the out of plane capacity check. The spacing required to partially restrain the column and rafter was determined to be 3600 mm. The design method adopted to calculate the design actions and required dimensions for the fly bracing was based off the method developed from the Australian Institute of Steel. [2] Further calculations of this may be seen in Chapter 13 Column Design and Chapter 11 Rafter Design of the final submission. The Fly bracing design specific calculations are detailed in Chapter 12 Fly Bracing Design.

IX. Purlins and Girt Design

I. C and Z purlins

The purlins and girts are designed to support the roof and wall sheeting for the maintenance hangar. They act principally as a beam, and a strut restraining the rafter and columns from lateral buckling. They also transfer the wind wall loads to the braced bays. They are cold formed z or c sections. The standard profiles are available from Stramit and Lysaght, who also provide design methods for their use. [28] Due to this, the Stramit profiles were adopted [28]. Z sections may be continuously lapped to provide a greater economy than a C section for medium to large buildings.[28] C sections, on the other hand are suitable for stability in single spans. As the Z sections are asymmetric, the uneven flange widths allow the sections to be lapped to permit structural continuity. This increase in length to achieve the structural continuity significantly increases the strength and rigidity of the purlin and girt. The strength obtained far exceeds the extra cost for the extra length. Due to this, the purlins and girts were designed using a Z section continuous span of 5 or more spans with a 15% lap [28].

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X. **Rafter and Column Design**

The design of the rafters and columns presented the option of using a fixed or pinned base plate, I beams or structural hollow sections, and the choice of using a haunch.

**J. Fixed or pinned base plate**

The design of the rafter presented the choice of designing for a fixed or pinned base plate. The use of a fixed base plate reduces the deflection of the frame due to the base plate absorbing some of the moment. This enables the use of smaller members. Pinned base plates are common in portal frame design due to ease of design and construction. Further to this, to achieve a fixed base plate connection, a thick base plate, a solid stratum and a low plasticity soil is required.

From the advice of professional engineers, a pinned base plate design was used. [55] The soil for the area is an expansive clay with a CBR of 1% and there is no record of a solid stratum in the geotechnical report [37]. Due to this, it was recommended the cost of a larger section for the columns and rafters would be more economical than fixing the base plates.

\[ \text{CROSS WIND LOADS - SERVICEABILITY} \]

![Figure 4. Lateral deflection (mm) output from Microstran using 1200WB392 sections](image)

**K. I beam selection vs structural hollow sections**

Structural Hollow sections are primarily used for long spans to reduce the dead load on the frame. [24] They have a high strength to weight ratio and are connected by welding. They may be circular, square, rectangular or oval shaped. As they generally have a consistent thickness for the outside material, they have a lower moment of inertia than an I beam in the principal direction of bending. They are cold formed and hence have less strength than an equivalent hot formed member.

I beams provide a larger moment of inertia in the direction of the inwards compressive force and outwards uplift force from wind. This is due to the size of the flanges compared to the web. Maximum material is provided to resist the largest bending moment that the structure may be subject.

As the structure was designed using a large single entrance for the aircraft a significant large outward bending moment in the rafters and columns occurs. The frames are subject to a large tributary area. Due to this, I beams were adopted to maximise the resistance to bending moment uplift force and satisfy strength and serviceability limit state requirements. I beams were adopted over I columns for the columns as there is no significant axial loading on the structure.

\[ \text{Figure 5. I beam and hollow section stiffness} \]

**L. Hot formed vs cold formed**

Hot Formed members were chosen in accordance with the ONE STEEL product manual [26]. This was based off the accessibility of hot formed members from ONE STEEL in Australia and the project location. Further to this, hot formed steel members have a higher strength capacity to cold formed structures and hence
will be more efficient. As stated previously, it will be subjected to significant wind up lift force with one open side and as such the connections will require this extra strength to ensure compliance with ASI Connection Design Guides and AS4100 [30] [12].

M. Haunches
The knee connection of the portal frame is subject to the largest outwards uplift moment and shear within the structure. Due to this, the connection is subject to significant design actions for the welds and bolts. Haunches were used to increase the distribution area. This also increased the stiffness of the structure and hence resistance to lateral sway.

While the use of a haunch increases the self-weight of the frame and hence the moment at the knee connection, the extra rigidity gained from its use outweighs this extra moment. Without the haunch, a larger deflection would occur and hence a larger section would be required.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig6.png}
\caption{Moment Design Actions from Microstran for uplift (kN)}
\end{figure}

XI. Connections
Due to the large scale of the structure and the large moments from a large uplift force, there were challenges to minimise the cost of each connection. The connections were designed in accordance with AS4100 [12] and the Australian Steel Institute Design Guidelines [30-35]. The Australian Steel Institute Design Guidelines detailed additional design checks not specified in AS4100. This was particularly pertinent with the base plate designs and knee connections.

N. Knee connection
The knee connection was subject to a large design moment. Due to deflection requirements, a large welded beam section was adopted for the rafter and column. As a result, the design of the connection was based off the minimum design action for the member. Though, it must be noted, there was minimal difference between this minimum design action and the design action from the uplift wind load combination acting on the structure.

As the connection was subject to a large design moment and shear force, the web and flange of the column required additional reinforcement. As stated within ASI Design Guide 12 [35], this may have been achieved through the use of doubler plates, a replacement flange plate and/or stiffener plates. Analysis was conducted for all three of these options. It was more economical and easier to detail the use of stiffener plates to enhance the capacity of the connection. This was due to the fact that the web and flange both required reinforcement. The use of a doubler plate for both was uneconomical. The effect of prying was considered in all connections.

ASI Design Guide 12 [35] recommended the use of multiple M24 bolts over increasing the size of the bolt. This was for economical purposes. Due to this an 8 M24 bolt configuration was adopted rather than a 4 M30 bolt configuration. The connection details may be seen in Appendix A. The design calculations will be in Chapter 14.2 Haunch Connection of the final submission.
O. Apex/ridge connection

The design of the ridge connection was unstiffened to compare the size requirements of the knee connection and size of bolts. It was designed in accordance with ASI Design Guide 10 Rigid Connections [34]. The ridge connection was subject to a large uplift force separating the two rafters. The moment within this connection is smaller than the moment within the knee connection, though, as detailed previously, the knee connection required smaller bolts and a smaller end plate section due to the use of a haunch. As can be seen in Chapter 14.3 Apex Connection Design of the final submission, the structure ridge required a much large end plate, weld size and high strength structural bolt. This significantly increased the price of the connection. The connection details may be seen in Appendix A. The design calculations are in Chapter 14.3 Apex Connection.

P. Base plate connection

The Base plate connections were designed in accordance with AS4100 [12] and the ASI Design Guide 7 [33]. Within this design guide, additional checks were conducted to ensure the capacity of the connection was adequate between the column and the footing pile.

As detailed previously, the connections were designed as pinned connections due to the nature of the soil. A base plate connection does not have any minimum design actions. [33] Due to this, the connection was subject lower design actions to the other connections. As a result, the design configuration of 6 M24 bolts with a welded beam was adopted. The connection details may be seen in Appendix A. The design calculations are in Chapter 14.1 Base Plate Connection and Chapter 14.5 End Wall Base Plate Connection of the final submission.

Q. End column design

The end column design was a lapped connection designed from simple beam theory. It was designed using the method stated within [2] and AS4100 [12] requirements. As the column was subject to minimal design actions, a universal beam was selected for the end wall column [26] (610UB101). Slotted holes were not used for the design. This was to eliminate the detailing difficulty in presenting the spacing required. Further, using non slotted holes is easier for construction. This was based off professional engineering advice. [55] Further, slotted holes present the potential for shearing failure. The connection details may be seen in Appendix A. The design calculations are in Chapter 14.4 End Wall Column Connection Design of the final submission.

XII. Bracing

The portal frame resists cross wind through in-plane flexure. Longitudinal wind forces on the other hand act on the end walls and entrance. These forces must be transferred from the roof to the side to the footings to prevent failure of the structure. This type of bracing consists of equal angles and pretensioned rods. The members are slender so as to have negligible capacity in compression. For double diagonal design, one of each bar acts in tension at any time. Due to this, in analysis, the other diagonal is ignored.

There is no universally accepted method for the design of bracing to deal with tension and self-weight of the bars. [2] Due to this, the method adopted within [2] was used for the design with AS4100 members in tension [12] requirements to reinforce the adequacy of the design.

R. Bracing plane and layout

To minimise difficulty in detailing, the bracing plane was chosen to be below the top flange to the mid height of the rafter. The following bracing layout was used for this design.

![Figure 7. left: Bracing plane at mid height of the rafter, right: bracing layout for two end frames](image)

This bracing layout is simplest and most direct method of design. [2] The end wall frame is the same as the designed frame for the structure, hence there is no detailing differences. The eaves and ridge struts provide stability during erection and general redundancy of structure. Further to this, the longitudinal wind forces may be transferred to the following bays through the purlins to reduce the magnitude of load on one area. Though, to
keep the design of the purlins simple and eliminate combined actions, the bracing was designed to resist loads from external pressure and internal suction on the adjacent end wall plus half the frictional drag forces.

S. Effect of pretension:

Pretension was considered in the design of the bracing. Pretension increases the yield capacity of the steel grade from 240 MPa to 300 MPa. With this, the tension in the compression diagonals will reduce. The tension in the alternate diagonal (tension) will increase. Essentially, from this, when the diagonals are subject to a compressive force, the diagonal will still be in tension [2]. The detailed design calculations of the bracing may be seen in Chapter 16 Bracing Design of the final submission.

XIII. Footing

The design of the footing must consider the uplift, compressive force and the foundation. With this in mind, a shallow footing foundation and a deep level foundation were investigated.

T. Shallow footing foundation versus deep level foundation

An initial shallow footing foundation was designed for the portal frame maintenance hangar to withstand the 160kN compressive force and distribute the load on a low strength soil (CBR 1). With the 420kN axial tension force from the wind uplift, the footing would require a depth of 2.5m with dimensions of 6m x 3m x 450 mm. The portal frame is 36m in length and each column would require this footing. With this in mind, and the substantial costs in excavation required to achieve this, deep level footings were investigated. It was judged that the amount of bars required was economically not advisable or suitable without having to increase the size of the footing.

Deep level foundations were investigated. The Additional depth of the footing provides a skin friction resistance between the footing and the soil. This significantly enhances the resistance to the uplift of the column.

U. Bored piles vs driven piles vs belled piers (drilled piers)

Driven piles displace clay laterally and vertically. This causes heaving of the ground surface and may reduce the clay bearing capacity and damage existing piles installed. The clay becomes completely remoulded in the disturbed zone. An excess pore water pressure is set up by the driving of the pile. Though, this pore water pressure dissipates before any significant structural load is applied. With this dissipation, shear strength and skin friction increases for the clay. [38]

Bored piles are cast on site by drilling. A thin layer of clay adjoining the shaft will be remoulded. Gradual softening occurs adjacent to the shaft due to stress release and pore water seeping from the clay to the shaft. Water is absorbed by the wet concrete. This softening reduces the shear strength and skin friction. Reconsolidation occurs after installation of the pile. [38]

As there was no evidence of the water table at the depth required of 7m and the spacing between each pile was 6 m, driven piles were used with the intent of using the increase in shear strength and skin friction. Due to this, the pre-cast concrete piles and driving machinery will be required.

The detailed design calculations are in Chapter 17 Footing Design of the final submission. These calculations were based of the friction resistance provided from the Cardno Bowler Geotechnical Report [37] and the pile design method detailed within AS2159: Piling Design and Installation. [9] The circular dimensions were converted to equivalent square dimensions to calculate the tensile capacity and squash capacity of the pile in accordance with AS3600 Concrete Structures. [11]

XIV. Foundation

V. Soil properties

From the Cardno Bowler Geotechnical report [37], the soil in the proposed location is an expansive clay with a plasticity index of 53. Due to poor drainage and the soft clays encountered from bore holes within the top metre across the site, the site was classified as Class ’P’ in accordance with AS2870-2011. Due to this, it was recommended that soil treatment was used to improve the quality of the soil. Recommendations included preloading, lime stabilisation and potentially PVD.

W. Treatment

There is no construction restriction time restriction for the project. Due to this, preloading and PVD’s will be used to improve the site conditions, hence reduce the moisture content and compressibility. From Ben Whytes’ recommendations, 600 mm would be stripped and replaced with CBR 10 select fill. The newly exposed surface is to be proof rolled using a minimum 10 vibrating padfoot roller drum. If there are any areas the contractors deems to be ‘soft’ are encountered over the area, it is to be removed and replaced with a select fill. Select fill is
also to be used for the fill of any removal of vegetation and underground services causing depressions in the surface. [37]

X. Settlement
Settlement of the foundation was calculated using the US Army Corps of Engineers (USACE) method [54]. Proposed in 1991, it is known as the Vesic method. Essentially the method calculates the vertical settlement of the top of a single pile by summing the vertical settlement of a pile tip due to load transferred at the tip and the vertical settlement at the pile tip caused by load transmitted along the pile shaft. From this method, a total settlement of 62.5 mm is recommended. From the calculations detailed in Chapter 17 Footing design, the maximum settlement will be 45 mm.

XV. Slab
The slab is to be loaded with maintenance equipment and the Alenia C-27J Spartan aircraft for short durations. According to [2], it must be designed to prevent the occurrence of:
- Excessive flexural stresses causing concrete cracking,
- Excessive bearing stresses on the concrete surface,
- Excessive punching shear due to the concentrated loads (aircraft),
- Differential deflection at joints,
- Excessive deflections due to the settlement of the subgrade, and
- Excessive cracking due to the shrinkage of the concrete.

Y. Design options
There are multiple options for the design of the slab and the materials used. These include:
- A rigid pavement, using a reinforced concrete slab,
- A granular flexible pavement,
- A cemented flexible pavement, and
- An unreinforced concrete slab.

An unreinforced concrete slab is common with airfields. [2] Though, to minimise cracking and potential water seepage, this was not adopted. A granular flexible pavement is designed primarily for medium trafficked pavements. As this is for a C-27J aircraft and maintenance equipment, this design option was not chosen. Similarly, the cemented flexible pavement was not adopted. Due to this, the rigid pavement using a reinforced concrete slab was adopted to minimise cracking and maintain the structural integrity of the slab during high loads with the C-27J and maintenance equipment.

Z. Design methods
There are various documents with empirical charts based on historical data to detail the design of slabs for aircraft. With this in mind, and noting there may be many other methods, two methods were adopted to design the slab. These include the CBR Flexible Pavement method and a Reinforced Concrete Airfield Pavement. Both of these are detailed in UFC 3-260-02 Pavement Design for Airfields. [47]

Flexible pavements are limited to airfield pavement areas not subjected to fuel spillage, severe jet blast or parked aircraft. Jet blast erodes the pavement and fuel spillages leach out the asphalt cement in asphaltic pavements. This may result in exposure of loose aggregate. [47] Rigid pavements are designed for 'all paved areas on which aircraft are regularly parked, maintained, serviced, or pre-flight checked, on hangar floors and access aprons’. [47] Consequently, a rigid pavement was adopted.

The rigid pavement may be:
- Plain concrete pavement with a nonreinforced jointed rigid pavement
- Reinforced concrete pavement - jointed rigid pavement that has been strengthened with deformed bars or welded wire fabric.
- Continuously reinforced concrete pavement - rigid pavement that is constructed without joints and uses reinforcing steel to maintain structural integrity across contraction cracks that form in the pavement.
- Fibrous concrete pavement - rigid pavement that has been strengthened by the introduction of randomly mixed, short, small-diameter steel fibers.
- Prestressed concrete pavement is a rigid pavement that has been strengthened by the application of a significant horizontally applied compressive stress during construction.

AA. Plain vs reinforced concrete vs fibrous concrete vs continuously reinforced concrete vs prestressed
Plain concrete is common for rigid pavements. [47] Though, reinforced pavements reduce the thickness of concrete required. It provides improved continuity across the cracks that develop from environmental factors or induced loading. As a result, there is less maintenance required. Due to this, a reinforced rigid pavement was
designed using [47]. From empirical charts within [47] for a medium aircraft, a slab of 12 m x 12 m x 280 mm was designed with 2% reinforcement steel. Additional design checks were conducted on the slab for flexural shear and punching shear for a stationary Alenia C-27J Spartan in accordance with AS3600 [11]. The full design may be seen in Chapter 18 Slab design of the final submission. This includes the aircraft classification, traffic area, number of passes calculation, and the tyre pressure from an Alenia C-27J Spartan.

Fibrous concrete pavement design involves the use of steel fibers to increase the flexural strength of the concrete. Though as this material is relatively new for pavement construction, it lacks long-time performance history. Due to this, it was not used for the hangar slab.

Continuously reinforced concrete pavements are applicable for any airfield pavement. The reinforcing steel is carried continuously in both the longitudinal and transverse direction. There has been limited experience with this style in airfield pavements and as such have minimal long time history performance records. Further to this, design of a continuously reinforced concrete pavement does not reduce the thickness of a plain concrete design. As such it would be less economical to use this over a reinforced concrete slab.

Prestressed Concrete Pavements uses a compressive stress induced in both the longitudinal and transverse directions prior to the application of the live load. This reduces the damage from tensile stresses resulting from the applied live loads. This allows the concrete to carry substantially larger loads to plain concrete and reinforced concrete of the same thickness. It requires complex joints and extreme care during construction to ensure over compression does not occur. Further, there is limited history of its use for airfield pavements outside Europe. Due to this, it was not adopted for the maintenance hangar slab.

**BB. Joints**

Reinforcement and load transfer at joints minimizes cracking. This also minimises any bumping across joints and reduces high flexural edge stresses as the load is continuously distributed. Typical joints include sawn, keyed and doweled. They are typically chosen from lightly loaded to heavily loaded respectively. [2] Using [47], 25 mm dowelled joints spaced at 410 mm were chosen for the slab. Further to this, at the columns, it is recommended that the slab is isolated from the column footing with a layer of compressible material around the footing. [2]

**XVI. Horizontal sliding door vs vertical lift doors**

Vertical lift doors require additional door leaves for a span greater than 19 m. [51] As the wingspan of the aircraft is 28.7m [19], vertical lift doors were not used. Further to this, a horizontal sliding system reduces the load on the steel frame.

While a horizontal sliding door was designed for this project, sizing components were conducted. A 4 door horizontal sliding system was researched and the design specification detailed within the sizing of the hangar. As there is no Australian documentation regarding the design requirements for a horizontal sliding door, US commonly used principles were adopted. To ensure tipping does not occur, a height to width ratio must be less than 3. [51] Using the 35 m space required for the wingspan, a width to height ratio of 2.07 was calculated for 4 horizontal sliding doors at 12m height. To fit this, 4m was provided into the hangar to store the doors with a width of 6 m. This is further detailed in Chapter 2, Sizing of the Maintenance Hangar of the final submission. With these doors, the hangar size was significantly increased. Due to this, an office, toilet and storage area for machinery were included in the extra space.

**XVIV. Project management**

The project management component of the project included an integrated critical path diagram and individual bill of materials.

**CC. Critical path diagram**

The critical path diagram was conducted using Microsoft Project as an integrated component of the project. As the development will be constructed with all the facilities concurrently, Daniel Parkinson, Ben Whyte and author conducted a group critical path diagram. This is in Appendix B with a supplementary individual construction process of the maintenance hangar.
This was broken down into the overall project requirements such as initial site set up and security. Ben Whyte’s construction commenced with the excavation of the site. Upon completion of the apron construction and curing time, the maintenance hangar and storage hangar construction sequence began. These were integrated to ensure plant such as the 25t Crane would be used on different days in the construction sequence. Further to this, materials for the slab and piles were ordered concurrently. Adequate time was provided to enable curing of the slab prior to the erection of the frames. The final elements were completed with a Troop of Construction Squadron allocated to Ben, Daniel and the author. Post the erection of the frames and bracing, the final components are to be conducted without dependence of each facility construction progress. The site clean-up was detailed, with a handover takeover period allocated and a defects liability of one year added.

**DD. Bill of materials**

The bill of materials was conducted using the Cordell estimator tool and additional publications for estimates on high strength structural bolts and welding. The cost of labour was not included in the estimate as the hangar is to be constructed by 21 Construction Squadron with any additional plant required sourced from contractors. The below table details a summary of the maintenance hangar material costs. Further detail of these may be found in Chapter 19, Bill of Materials of the final submission.

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>COST $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour (sourced from a Construction Squadron)</td>
<td></td>
</tr>
<tr>
<td>Structural Steel</td>
<td></td>
</tr>
<tr>
<td>Main Elements</td>
<td>$402,991.24</td>
</tr>
<tr>
<td>Main Frame Base Plate Connection</td>
<td>$30,497.75</td>
</tr>
<tr>
<td>End Wall Base Plate Connection</td>
<td>$4,150.29</td>
</tr>
<tr>
<td>Apex Connection</td>
<td>$14,056.92</td>
</tr>
<tr>
<td>End Wall Ridge Connection</td>
<td>$2,249.54</td>
</tr>
<tr>
<td>Haunch Connection</td>
<td>$32,385.43</td>
</tr>
<tr>
<td>Bracing Connection</td>
<td>$22,616.66</td>
</tr>
<tr>
<td>Side Brace Connection</td>
<td>$13,871.50</td>
</tr>
<tr>
<td>Cladding</td>
<td>$45,535.20</td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
</tr>
<tr>
<td>Slab and Piles</td>
<td>$377,563.33</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
</tr>
<tr>
<td>Internal fittings</td>
<td>$21,805.81</td>
</tr>
</tbody>
</table>

**XVII. Conclusion**

The ADF procurement of the Alenia C-27J Spartan aircraft has resulted in the requirement of an airfield training facility to enhance air logistic support and airborne operations within the regional responsibilities of Australia. As an integrated design team, structural designs for facilities of an airfield used solely for the C-27J were developed. Australian Standards, Australian Steel Institute Design Guidelines, the Building Code of Australia, The Manual of Fire Protection, and United States Air Force Maintenance Hangar documentation were used to determine the methodology of the design. Design actions were calculated using an elastic analysis from Microstran. From these design actions, the strength and serviceability limit state requirements for Australian Standards were satisfied in the design of the columns, rafters, connections, fly bracing, purlins and girts, and the footings and slab.

Fundamental concepts for structural steel design, concrete structures, geotechnical engineering, and project management were consolidated with a design scenario currently facing ADF personnel. Subsequently, the team was provided the opportunity to engage professional engineers and gain knowledge in current industry wide practices and preferred methods of design. An understanding of time required was gained from developing a design of a complete structure. Project management components were integrated to provide a consolidated understanding of working in a team to achieve completion of a full project with multiple facilities being constructed concurrently.
Appendix A

A. Designs

![Diagram of a maintenance hangar with dimensions and annotations]

- **Sign:** A
- **Format:**
- **Designed by:** LT Atkinson
- **File:** 1/10
- **Date:** 21/10/13
- **Scale:** 1:200
- **Title:** Maintenance Hangar
- **3D Views**

Note: The side walls are isometric.
Appendix B

A. Critical Path Diagram overall project construction

The following critical path diagram details the overall components of the project construction. This includes the initial site set up, the pavement construction, storage hangar and the maintenance hangar.
B. Critical Path Diagram – Maintenance Hangar

The following gantt chart details the maintenance hangar critical path diagram in more detail with each component detailed.

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building - Maintenance Hangar</td>
<td>62 days</td>
<td>Tue 24/5/14</td>
<td>Wed 15/6/14</td>
</tr>
<tr>
<td>Foundation</td>
<td>10 days</td>
<td>Tue 20/5/14</td>
<td>Fri 23/5/14</td>
</tr>
<tr>
<td>Excavation of slab area 31.5 x 47 m, 800 mm deep</td>
<td>3 days</td>
<td>Tue 20/5/14</td>
<td>Thu 22/5/14</td>
</tr>
<tr>
<td>Select 18 and compact 156 mm each layer CBR</td>
<td>5 days</td>
<td>Fri 23/5/14</td>
<td>Thu 29/5/14</td>
</tr>
<tr>
<td>Geotechnical inspection of the soil</td>
<td>3 days</td>
<td>Fri 23/5/14</td>
<td>Wed 28/5/14</td>
</tr>
<tr>
<td>Drivers Lift</td>
<td>2 days</td>
<td>Tue 3/6/14</td>
<td>Wed 4/6/14</td>
</tr>
<tr>
<td>Drive piles installation</td>
<td>2 days</td>
<td>Thu 6/6/14</td>
<td>Wed 12/6/14</td>
</tr>
<tr>
<td>Steel</td>
<td>1 day</td>
<td>Thu 13/6/14</td>
<td>Thu 19/6/14</td>
</tr>
<tr>
<td>Lay reinforcement, Choir, Pits</td>
<td>2 days</td>
<td>Thu 20/6/14</td>
<td>Fri 21/6/14</td>
</tr>
<tr>
<td>Cast concrete, sides 12 m x 12 m x 200 mm</td>
<td>1 day</td>
<td>Mon 24/6/14</td>
<td>Mon 30/6/14</td>
</tr>
<tr>
<td>Concrete Cure tree</td>
<td>3 days</td>
<td>Tue 24/6/14</td>
<td>Fri 27/6/14</td>
</tr>
<tr>
<td>Steel Order and workshop fabrication</td>
<td>10 days</td>
<td>Fri 27/6/14</td>
<td>Thu 17/7/14</td>
</tr>
<tr>
<td>Order, fabrication, Hit and launch, others</td>
<td>15 days</td>
<td>Fri 27/6/14</td>
<td>Thu 17/7/14</td>
</tr>
<tr>
<td>Order and delivery cast rail 940 members</td>
<td>10 days</td>
<td>Fri 27/6/14</td>
<td>Thu 17/7/14</td>
</tr>
<tr>
<td>Steel Construction Sequence</td>
<td>10 days</td>
<td>Fri 10/7/14</td>
<td>Fri 4/8/14</td>
</tr>
<tr>
<td>Frame construction 5 frames</td>
<td>2 days</td>
<td>Fri 10/7/14</td>
<td>Mon 28/7/14</td>
</tr>
<tr>
<td>Ridge connection</td>
<td>2 days</td>
<td>Fri 17/7/14</td>
<td>Mon 21/7/14</td>
</tr>
<tr>
<td>Knot Connection</td>
<td>2 days</td>
<td>Fri 18/7/14</td>
<td>Mon 21/7/14</td>
</tr>
<tr>
<td>Roof and two frames</td>
<td>2 days</td>
<td>Tue 22/7/14</td>
<td>Fri 25/7/14</td>
</tr>
<tr>
<td>Base rail connection</td>
<td>1 day</td>
<td>Tue 29/7/14</td>
<td>Wed 30/7/14</td>
</tr>
<tr>
<td>Stab connections</td>
<td>1 day</td>
<td>Wed 22/7/14</td>
<td>Wed 22/7/14</td>
</tr>
<tr>
<td>Bracing the two frames</td>
<td>1 day</td>
<td>Wed 29/7/14</td>
<td>Wed 30/7/14</td>
</tr>
<tr>
<td>End wall, Covers, connections and base</td>
<td>1 day</td>
<td>Tue 25/7/14</td>
<td>Tue 25/7/14</td>
</tr>
<tr>
<td>Scaffolding &amp; 4 frames</td>
<td>2 days</td>
<td>Fri 4/8/14</td>
<td>Mon 11/8/14</td>
</tr>
<tr>
<td>Baking frame</td>
<td>1 day</td>
<td>Thu 28/7/14</td>
<td>Thu 29/7/14</td>
</tr>
<tr>
<td>Purse and Grid (short from rear frame)</td>
<td>2 days</td>
<td>Fri 24/7/14</td>
<td>Wed 29/7/14</td>
</tr>
<tr>
<td>Roof insulating siding/Door</td>
<td>4 days</td>
<td>Thu 31/7/14</td>
<td>Tue 5/8/14</td>
</tr>
<tr>
<td>Fixing</td>
<td>1 day</td>
<td>Wed 6/8/14</td>
<td>Wed 6/8/14</td>
</tr>
<tr>
<td>Lighting</td>
<td>2 days</td>
<td>Thu 7/8/14</td>
<td>Fri 8/8/14</td>
</tr>
<tr>
<td>Materials Order and Fabrication</td>
<td>6 days</td>
<td>Fri 10/8/14</td>
<td>Tue 14/8/14</td>
</tr>
<tr>
<td>Damage materials (pattressing and de-mo)</td>
<td>6 days</td>
<td>Fri 10/8/14</td>
<td>Tue 14/8/14</td>
</tr>
<tr>
<td>Internal partitions, r.o. equipment</td>
<td>7 days</td>
<td>Fri 10/8/14</td>
<td>Fri 17/8/14</td>
</tr>
<tr>
<td>Accessory equipment</td>
<td>6 days</td>
<td>Fri 10/8/14</td>
<td>Mon 17/8/14</td>
</tr>
<tr>
<td>Drainage</td>
<td>1 day</td>
<td>Mon 11/8/14</td>
<td>Mon 11/8/14</td>
</tr>
<tr>
<td>Roof gathering and drainage instal</td>
<td>1 day</td>
<td>Mon 11/8/14</td>
<td>Mon 11/8/14</td>
</tr>
<tr>
<td>Internal fittings</td>
<td>3 days</td>
<td>Mon 11/8/14</td>
<td>Wed 13/8/14</td>
</tr>
<tr>
<td>Internal partitions</td>
<td>3 days</td>
<td>Mon 11/8/14</td>
<td>Wed 13/8/14</td>
</tr>
<tr>
<td>Accessories facility installation</td>
<td>2 days</td>
<td>Mon 11/8/14</td>
<td>Wed 13/8/14</td>
</tr>
<tr>
<td>Office installation and lighting</td>
<td>2 days</td>
<td>Mon 11/8/14</td>
<td>Tue 12/8/14</td>
</tr>
</tbody>
</table>
References

Overall

Australian Standards

Hangar Sizing

Structural steel

Purlins, girts, cladding

Connections

**Foundation and footings**
37. Cardno Bowler, *Cardno Bowler APOD Project Old Toowoomba Road, RAAF Base Amberley Job Number 10223dr.11*, Australia, 02 November 2011.

**Slab**

**Detailing**

**Hangar Doors**

**Miscellaneous**

**Professional Practicing Engineer**
55. Ian Hooley, lecturer at UNSW Canberra, email correspondence.