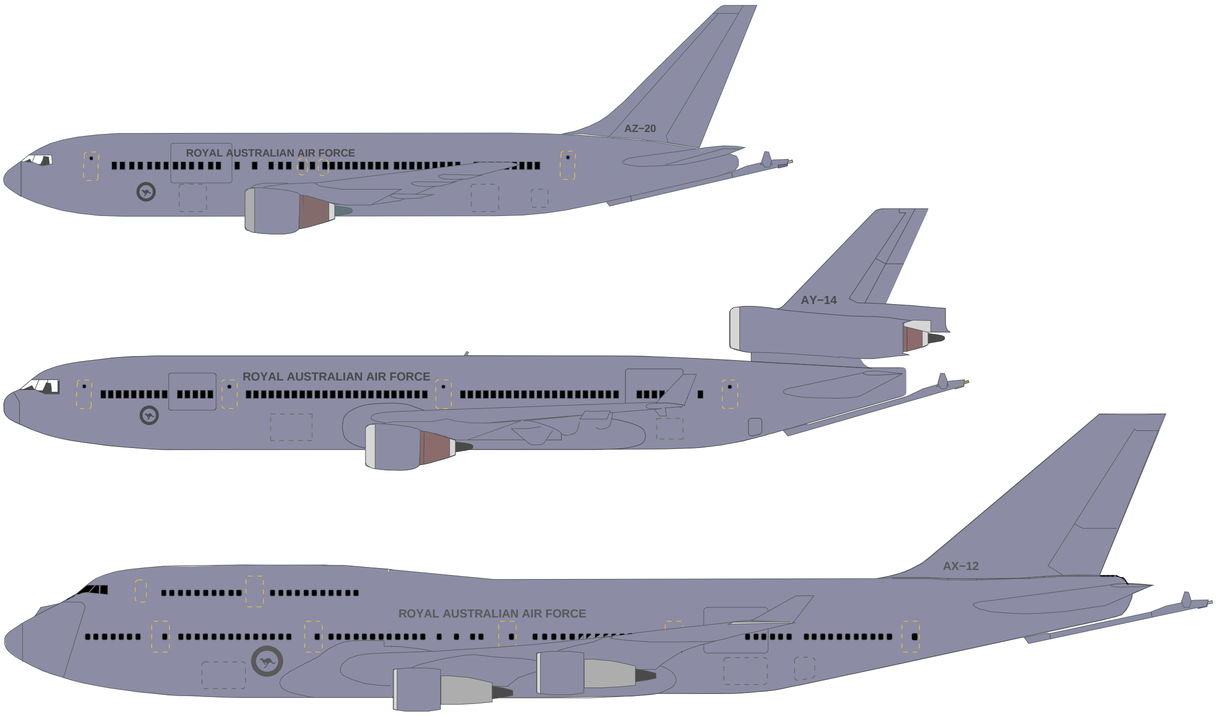

Aerial Refuelling for the ADF: Strategic, Operational and Technical Issues

Carlo Kopp, BE(Hons), MSc, PhD, PEng,
Defence Analyst and Consulting Engineer
Email: Carlo.Kopp@aus.net

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Figure 1: *The RAAF has four Boeing 707-338C tankers, to provide a training and limited operational capability. In numbers these aircraft are inadequate to meet future needs, despite their excellent airframe design for the role. The RAAF's Boeing 707-338C tankers have much remaining performance and capability potential which could be exploited by fitting CFM56 or JT8D-219 turbofans, lower deck fuel cells, an APU package, a refuelling boom and a glass cockpit, utilising hardware common to the KC-135R series. The decisive issue which will lead to their retirement is dealing with corrosion, structural fatigue, electrical wiring deterioration and aging of other aircraft components, the repair costs alone being similar to the market value of a used 767 or 747 aircraft (RAAF).*

1 Introduction

Should Australia aim to address the stated capability goals in the new White Paper, the RAAF will face four major capability growth challenges over the coming decade. These will be the integration of AEW&C, selection of a Hornet replacement, deployment of a strategic reconnaisance capability and importantly, significant expansion of aerial refuelling capabilities.

Aerial refuelling has been, in a sense, a Cinderella in the public defence debate. Fighters evoke intense emotion in public debate, AEW&C impresses all with its high technology sophistication, while satellite and UAV reconnaissance systems carry the mystique of secrecy. Tankers offer none of these exciting attributes, yet they are the backbone of any modern air force, and perhaps the decisive element in every aerial confrontation since Vietnam.

This paper will take a broader look at the problems the RAAF will face in this area, and illustrate that in its own way, aerial refuelling capability is no less challenging than other components of modern air power.

2 Fighters and Aerial Refuelling

Tankers are often portrayed as a panacea for all limitations in fighter endurance and range. Indeed, a popular myth is that enough tanking can make a lightweight fighter competitive with a heavyweight fighter. Reality is however a little more complex.

Aerial refuelling is used to support fighters in a number of ways. Long range deployment will see fighters cross intercontinental distances with tanker support. Defensive Counter-Air (DCA) will see fighters and supporting AWACS/AEW&C orbit for many hours beyond their design endurance on internal fuel, refuelled by tankers. With tankers, Offensive Counter-Air (OCA) and Land/Maritime Strike operations will see fighters reaching out to engage air and surface targets at distances well beyond their design combat radius. Range and endurance unlimited? Not quite.

The basic constraint to all aerial refuelling of fighters is that whenever a fighter lines up on a tanker to take on fuel, it should have enough fuel remaining in its tanks to make it back to a friendly runway safely. If this is not the case, failure of the refuelling equipment, be it probe/drogue or receptacle/boom, will see the fighter lost due to fuel exhaustion. While such failures are infrequent, they do happen. The RAAF on two occasions had to jettison hoses with damaged drogues, and the US Air Force snaps a tanker boom every once in a while. As infrequent as such events are, they are a fact of life. The cost of fighters and high risks to aircrew mean that prudent operational practice is to budget with this possibility.

Figure 2: *While aerial refuelling is vital to achieving persistence in combat and extending fighter operating radii, it is not a panacea for inadequate fighter sizing. The operating radius of the fighter sets limits on diversion ranges and Combat Air Patrol station radii, both of which decisively favour larger fighters in Australia's geography. The F-22A is the only new technology fighter in this class, with an internal fuel capacity close to 220% of the RAAF's F/A-18A (US Air Force).*

In this sense, aerial refuelling is not a substitute for large fighter operating radius. Consider the simple scenario of a fighter Combat Air Patrol (CAP) orbiting some distance over the ocean, to stop a potential cruise missile attack. This is a 'real world' scenario given developing regional capabilities.

The scenario can be approached in two ways. The first is that a tanker is orbiting in the CAP station area, CAPs fly out to station, top up their fuel to gain time on station, and then depart once their planned mission duration is up or they have expended their missile load in combat. In this model, the tanker only performs the task of providing endurance on station, while the distance to the CAP station is limited wholly by the fighter's internal and external fuel capacity.

An alternative approach to this model is to sortie a tanker with the CAP, and have the fighters continually top up until they reach their CAP station, upon which they continue top up to maintain enough fuel to safely recover. This approach allows the CAP to orbit at greater distances, but also forces the need for more frequent aerial refuelling to remain on station. At all times the fighters must carry enough fuel to safely recover, plus their combat gas reserve for an engagement, and fuel to burn on orbit until the next refuelling.

Smaller fighters fall down very quickly in this model, since they will be going into an engage-

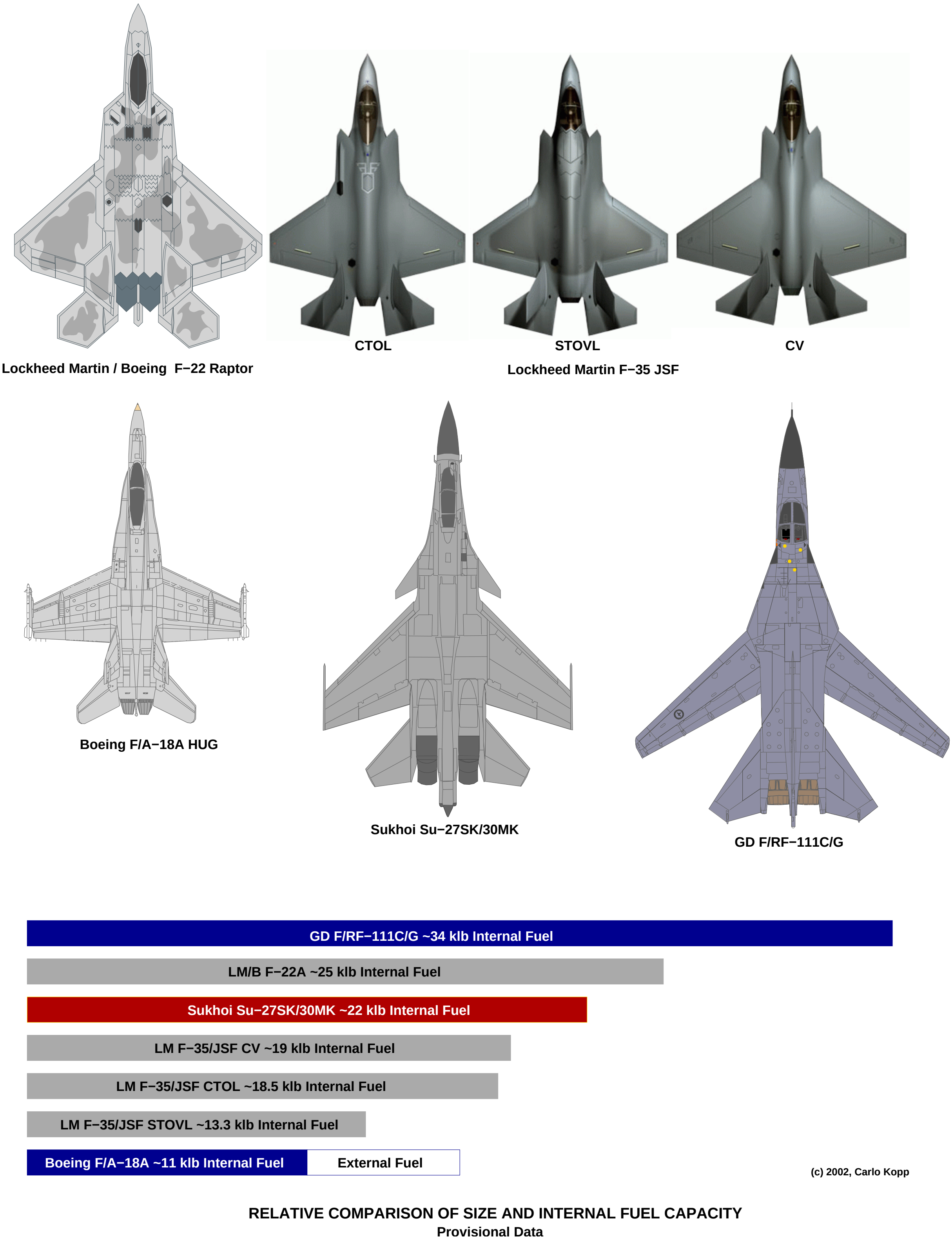

Figure 3: *Comparison of representative combat aircraft (Author, Lockheed-Martin).*

ment at weights much heavier than their optimal or design combat weight, thus losing most of their agility. Indeed, all fighters have structural G limitations at higher weights and many may be unable to manoeuvre aggressively if loaded up to 75% or more of total internal and external fuel capacity.

Larger fighters, with 'big bore' engines, can accommodate this regime of operations much better. Designed for larger combat radii, they will be operating at weights much closer to their design or optimum combat weight. The structural redesign of the F-15E for 9G, against the 7.33 G rated F-15C, was no accident.

Large fighters do provide for some economies in aerial refuelling, but this is not for the simplistic reason that they can operate without refuelling when small fighters cannot. The reality is that the cruise fuel burn of a F/A-18 sized fighter does not differ dramatically from that of an F-15 sized fighter. Cruise burn is dominated by transonic drag, and whatever total weight advantage the small fighter has is offset by the higher drag resulting from more external gas tanks.

A large fighter will therefore need to take on a similar amount of gas over the sortie, to what the small fighter does, to achieve similar endurance on station.

The difference results from the reality, that a CAP of small fighters must fly out, remain on station, and return 'towed by a tanker' since they need to continually top up to maintain a safe margin of fuel to get home with. A large fighter can operate at similar CAP radii without being closely tied to the tanker. Indeed, the tanker may be sortied independently of the large fighters, which only take on fuel once on station, to extend endurance.

Therefore, large fighters allow the economy of smaller numbers of tankers, and larger tankers which produce economies in aircrew, total support and fuel burn per tonne of fuel offloaded. Small fighters push the numbers of tankers up, and push their size down, since the fuel needs to be moved around in smaller chunks, and more tankers need to be in more places at once.

Another issue is the potency of a fighter. Consider a fighter fleet comprising 80 F-15 fighters - if they are replaced with 40 F-22s this yields a greater total fleet combat capability, yet the demand for tanker fleet size is close to halved. Large numbers of low capability fighters will always impose bigger demands upon tanker fleet size than smaller numbers of high capability fighters, to achieve the same total effect. If tanker fleet size is factored in, then 'small cheap fighters' really amount to 'big expensive fleet' fighters. Finding enough pilots to fly them and the supporting tankers is yet another issue.

These issues underscore the complexity of tanker fleet sizing analysis, and the implicit interrelationships between fighter size, capability and tanker size.

If strike radius and CAP station radius matter, then the most general conclusion which can be

Figure 4: *The outstanding success of the recent bombing effort in Afghanistan would have been impossible without the use of aerial refuelling, which allowed US Air Force and US Navy combat aircraft to strike at targets from distances ranging between 1,000 and 2,500 nautical miles. The key to the success of air power against mobile and fleeting ground targets was the use of innovative 'loitering bombardment' techniques, critically dependent upon aerial refuelling. With mobility becoming a favoured defence against air power, 'loitering bombardment' will become a central aspect of future air operations, further increasing the demand for aerial refuelling (US Air Force).*

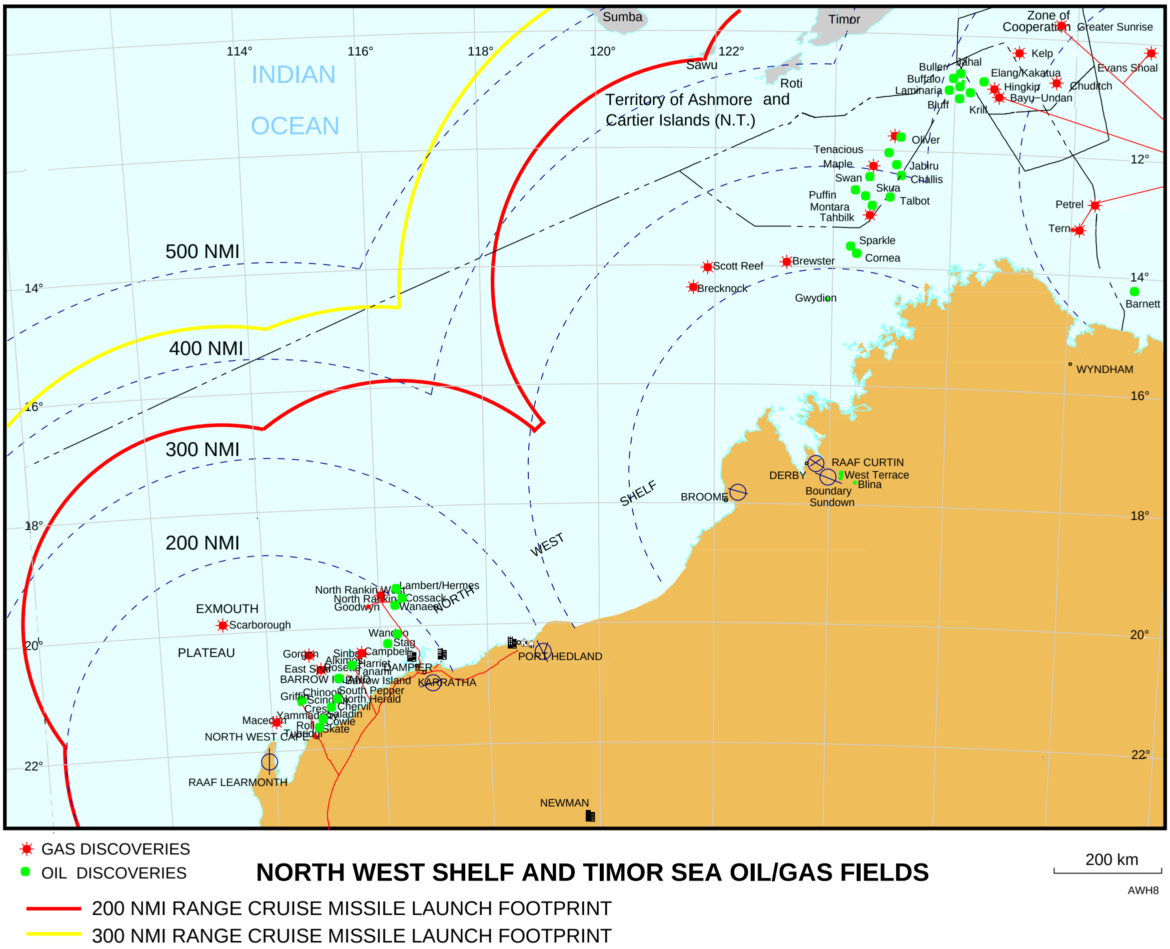

Figure 5: *The North-West Shelf and Timor Sea air defence environment is challenging due to the low density of runways, large distances and widely spread oil and gas facilities which represent lucrative strategic targets in times of tension or war. The rapid development of the energy industry in the Deep North has unfortunately coincided with a period in which latest generation Russian weapons, especially cruise missiles, have proliferated across the wider region (Author).*

Figure 6: *An important advance in the recent White Paper is a firm commitment to provide boom equipped tankers to support the F-111 fleet (Upper) in the long range strike and sea control roles, vital to the regional 'denial strategy' which underpins the document. With tanker support, US Air Force F-111F and EF-111A (Lower) aircraft flown in the El Dorado Canyon strike against Libya remained airborne for almost 14 hours, this amounting to an effective combat radius of about 3,000 nautical miles (RAAF, F-111.net).*

Figure 7: *The RAAF's F-111C/G aircraft employ the US Air Force standard boom refuelling system, unlike the F/A-18A which uses the US Navy/RAF standard hose/drogue refuelling system. Coalition operations with allies might involve refuelling aircraft using either system, therefore the RAAF's new tankers must have facilities for both. The existing Boeing 707-338C tankers are not equipped with booms (RAAF).*

drawn is that 'bigger is better', both for fighters and tankers, and economies accrue to those players who exploit this cleverly.

3 Refuelling Other Types

While the provision of aerial refuelling for the F/A-18A, its replacement, and the F-111 and Wedgetail AEW&C fleets, will remain the top priorities for the RAAF, a robust tanker fleet would produce significant benefits in other areas of operation.

Maritime patrol work involves long endurance sorties, and the RAF has frequently used aerial refuelling to stretch the on station endurance of its Nimrod aircraft. Whether the AP-3C replacement is another P-3 derivative, or a 737-700 IGW derivative, the latter in the running for the USN's P-3 replacement, a 1,500 NMI radius with 3-4 hrs on station can be significantly stretched by the use of tankers. This can be especially valuable when defending sea lanes, or prosecuting a submarine once contact has been made.

Airlift operations can also benefit from aerial refuelling. While the ADF is unlikely to be challenged with the global deployment needs of the US Air Force, some peacekeeping commitments will require global range. Of more concern is that many runways in the nearer region are of woeful quality and length, and this will often severely limit airlifter takeoff and landing weights. Having the opportunity to gas up after takeoff from such a runway removes this problem as a critical constraint to operations.

Whether tanking is used to extend AEW&C, maritime or airlift resources, the common factor in all is that large volumes of fuel may need to be offloaded from the tanker. The receiver aircraft will carry 20-30 tonnes of internal fuel, and heavier airlifters even more. Therefore a top up by a tanker might require anything from 10 to 20 tonnes of fuel, many times the offload required per fighter.

The central conclusion is that a robust tanker fleet can produce large gains, no matter which way it is used.

4 Crewing a Tanker Fleet

Crewing fleets of tankers is a major issue, and is closely related to fleet sizing. An unavoidable reality is that full utilisation of a fighter force requires that some ratio of total tanker numbers/capacity to fighters must be satisfied, otherwise many fighters will go without refuelling support. In Australia's geography, where potential assets to be defended are widely dispersed across the north, and suitable runways sparse, scenarios would have to be contrived to justify the case for fighters being flown without aerial refuelling support. Australia is not Europe or the Middle East, and what amounts to a reasonable combat radius in that part of the world is by basic geography utterly irrelevant to Australia.

During the latter part of 1999, the author produced a 140 page study on strategic tanking, published in March 2000 by the RAAF Aerospace Centre. Extensive computer simulations were performed to gather hard numbers for this task[1].

The most interesting conclusion of this study was the required number and size of aerial refuelling tankers to address the RAAF's current shortfall in capability. Three separate models were used to produce a fleet size estimate. One was based wholly upon defensive Combat Air Patrols in the Pilbara, another was based upon regional long range power projection, and the third was based upon scaling the ratio of fighters to tankers, used by the US Air Force and Royal Air Force, against the number of F/A-18s and F-111s in the RAAF force structure. All three estimation models yielded almost identical results.

These results indicated that should the RAAF aim to properly address this capability, it would need to field either 12-16 heavy tankers (in the class of the Boeing 747 or Boeing DC-10), or 20-30 medium tankers (in the class of the Boeing KC-135R, Boeing 707-320, Boeing 767-200 or Airbus A330), or some High-Low mix of heavy and medium tankers. A heavy tanker can offload roughly twice the fuel which a medium tanker can offload.

While specific assumptions made in the sizing analysis can be debated further, the order of magnitude will not change significantly. The US Air Force experience since the 1950s is the bottom line - for every 100 fighters, around 25-30 medium tankers or 12.5 heavy tankers are needed to provide robust aerial refuelling support. The commitment to 5 tankers in the White Paper is at best a 'half-measure' and this will need to be addressed with proper funding over the next decade.

The big issue the RAAF will face with aerial refuelling is that of crewing a tanker fleet. Difficulties will arise especially in training qualified tanker commanders. On the other hand, the capital costs of 12-30 tankers are comparable to those of 12-30 new fighters, which are significantly lower than upcoming programs such as AIR 6000.

The US Air Force Doctrine Document 2-6.2, 'Air Refuelling', provides an excellent indication of needs in tanker crewing, empirically learned over five decades.

For 'intertheater' aerial refuelling, comparable to long range land and maritime strike aerial refuelling support in the ADF context, an aircrew to aircraft ratio of 1.65:1 allows full utilisation of the available aircraft. This assumes the aircraft each fly 9.9 sorties per week, each of 12

[1] RAAF APSC Working Paper No.82 'A Strategic Tanker/Transport Force for the ADF' refer http://www.defence.gov.au/aerospacecentre/publish/paper82.htm.

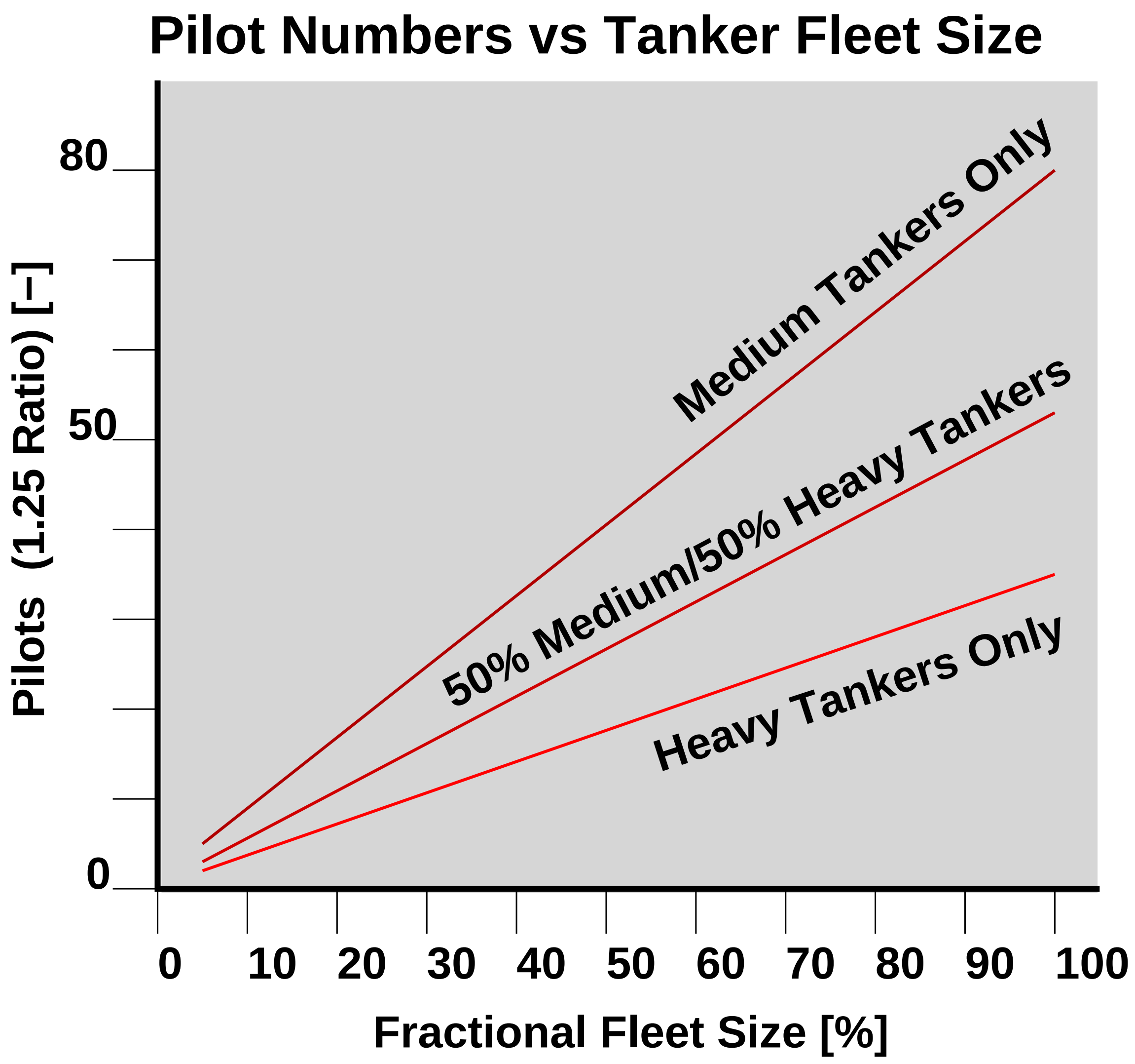

Figure 8: *The most difficult problem the RAAF will face in future tanker fleet expansion will the the recruiting, training and retention of adequate numbers of pilots, especially qualified tanker commanders. Full utilisation of a tanker fleet requires a 1.6:1 or greater ratio of crews to aircraft, with each crew comprising a commander, copilot, most likely also a flight engineer and refuelling equipment operators.*

hours duration, under which conditions the aircraft spend 70% of the time airborne.

For ‘intratheater’ aerial refuelling, comparable to defensive combat air patrol aerial refuelling support in the ADF context, an aircrew to aircraft ratio of 1.62:1 allows full utilisation of the available aircraft. This assumes the aircraft each fly 19.4 sorties per week, each of 4 hours duration, under which conditions the aircraft spend 46% of the time airborne. Extending the average duration of the sortie will provide better utilisation of the aircraft, although this is unlikely to strongly impact the ratio of aircrew to aircraft.

Should allowances be made for spare aircrew, instructor pilots and pilots redeployed in staff positions, an aircrew to aircraft ratio much closer to 2:1 would result. In the simplest of terms, for every tanker aircraft close to two aircraft commanders and two copilots would be required.

If the fleet is to be sustainable, that is have the capacity to perform high intensity operations for several consecutive months, as may occur in a crisis situation, then even a 2:1 crewing ratio may not be adequate. This is because crews can only put in a finite number of flight hours per week and month, not to exceed safe fatigue levels.

The US Air Force makes substantial use of the Air Force Reserve (AFRes) and Air National Guard (ANG) to crew their fleet of around 600 tankers. Roughly 50% of the tanker fleet is crewed by AFRes and ANG personnel, many of whom have ‘weekday’ jobs as commercial pilots.

Should the RAAF aim for a tanker fleet with credible aggregate size, depending on the mix of medium and heavy tankers used, a total of 24 to 48 command qualified pilots, and 24 to 48 first officer qualified pilots would be required. Should one half of these be drawn from active reservists flying for the airlines, the RAAF would still need to maintain 12 to 24 full time pilots in either category. If a minimal ratio of aircrew to aircraft is maintained, such as 1.25:1 as the US Air Force do at this time, the requirement drops to about 15 to 30 pilots in total, in either category.

These order of magnitude numbers cannot be substantially altered, at best the burden can be shifted to a higher proportion of active reserve aircrew in the employ of the commercial airlines. Withdrawing, at short notice, such a number of reservists from the airlines would however impact operations for the airlines, especially if they are also subjected to ADF demands for second echelon civil airlift. Reliance upon the US Air Force to provide adequate aerial refuelling assets is yet another instance of shifting the burden elsewhere, in this instance upon the US taxpayer. Given that the US Air Force tanker fleet is already undercrewed, such a strategy incurs the risk of the US not being able to provide the resource in a crisis situation. Needless to say, leasing the tankers changes the equation very little, if the aircraft are to be flown in a combat situation.

Of all the obstacles the RAAF will face in a future expansion of aerial refuelling capabilities, the crewing problem will by far be the most difficult one to resolve.

5 Ground Infrastructure

The support of a substantial operational tanker fleet does not end with acquiring aircraft and finding and training enough pilots. The aircraft must be maintained, and the bases from which they operate must have sufficient fuel replenishment capabilities to support the required operational tempo.

Given judicious choices in aircraft types and powerplants, most of the support burden can be shifted to existing airline operators, who already maintain substantial fleets of similar or identical types. Indeed, sharing facilities such as flight simulators further improves upon this.

A much bigger issue for the RAAF is the provision of adequate aviation kerosene supplies to the more remote bases in the north of Australia. Strategically, the four most important bases are RAAF Learmonth, RAAF Curtin, RAAF Tindal and Darwin airport. Only Learmonth and Darwin at this time have runways which are rated for the use of heavy tankers at high gross takeoff weights.

Sustained high intensity operations by a substantial proportion of the RAAF fast jet force, fully supported by proper numbers of tankers, would consume many hundreds of tonnes, or more, of aviation kerosene per 24 hour cycle. While underground storage tanks with 10,000 - 20,000 tonnes capacity, installed at Darwin, Learmonth and possibly Curtin, would buffer the demand during short notice or surge operations, proper replenishment would be required to sustain operations at this tempo. This is unlikely to be feasible using tanker trucks on northern highways.

Fortuitously, the two most relevant runways, Darwin and Learmonth, are situated sufficiently close to the coast to allow for a shipping pipeline to be provided to a loading jetty. In this manner a tanker ship can be used to replenish on site storage at a sustainable rate.

Another important factor to consider is the recently initiated Syntroleum Sweetwater project for a Gas-To-Liquids (GTL) synthetic crude oil production plant, being built close to Karratha in the Pilbara (http://www.syntroleum.com). Such plants use a derivative of the synthetic fuel production technology used by Germany in WW2, replacing the coal feedstock with natural gas. This plant and technology are very attractive for two reasons. The first is its proximity to Learmonth and Curtin, which cuts fuel transportation costs and shipping delays. The second reason is that a synthetic JP-8 / Jet A type fuel could be made with virtually zero sulphur and heavy metal content, and precisely controlled aromatic content, thereby reducing jet engine corrosion and 'coking' in combustors and burners, respectively.

The current thrust in the GTL industry is to produce 'environmentally friendly' synthetic gasoline, diesel and high purity hydrocarbon feedstocks. Aviation kerosene as a smaller market has yet to attract the industry's focus, but given the high cost of engine overhauls and progressively declining quality of natural crude oil stocks, the long term drivers would favour such a fuel.

A good case can be made for Australia to be self sufficient in the production of aviation kerosene, which is vital for the ADF and the commercial airlines. The 10,000 BBL/day total capacity Sweetwater plant, even if configured for aviation kerosene production, would not have the capacity to meet the needs of high intensity RAAF operations in the north-west. However, should plant capacity be increased 5-10 fold in coming years, then it would be able to meet such needs. Under such conditions a good case could be made for building a runway at Karratha with sufficient length and load bearing capacity to support heavy tanker aircraft, as the cost of a kerosene pipeline from the Sweetwater plant to RAAF Learmonth is arguably sufficiently high to justify tanker operations from Karratha.

It is worth noting that the Allied Force air campaign against Serbia relied critically upon the NATO network of fuel pipelines, which were used to replenish NATO air bases in Italy and Germany. The availability of substantial fuel supplies to bases in Saudi Arabia was pivotal to the sustainability of the Desert Storm campaign in 1991.

What the cost of proper fuel replenishment might be remains to be exactly determined. Underground concrete fuel tanks and plumbing are not particularly expensive. The political complexities of securing domestic self sufficiency or secure wartime kerosene supplies may prove to be the bigger issue.

6 Choice of Aircraft for Tanker Conversions

A critical issue in a future expansion of the RAAF tanker fleet is the choice of aircraft type. Unlike more complex military aircraft such as fighters or AWACS, tankers incur negligible technological risk. Conversion of an airliner or freighter into a tanker involves often extensive structural changes, addition of refuelling equipment, plumbing and pumps, wiring for controls, and optionally additional fuel tanks in the lower deck baggage area.

The principal risk faced in tanker buys is that of injudiciously choosing an aircraft type which disappears from the commercial fleets well before the air force owned tanker variant runs out of airframe fatigue life. If the disparity is too great, the long term cost of supporting the tanker variant can become prohibitive.

This is because military tankers accrue flight hours, and thus airframe fatigue, much more slowly than their airline operated siblings. The US Air Force are now facing this very problem with their fleet of KC-10 Extender tankers, based on the commercial DC-10. The commercial DC-10 fleet will run out of life around 2010-2015, leaving the US Air Force with the burden of supporting an orphaned aircraft with one half or less of its fatigue life expended. The US Air Force KC-135 fleet is cited at 14,500 hrs airframe time, on average, yielding a fatigue life until 2040.

A useful side effect of the different rate at which fatigue is accrued in tankers is that 7-12 year old used airliners are a much better buy than new build aircraft, and at this age most used airliners cost a small fraction of the cost of a new aircraft.

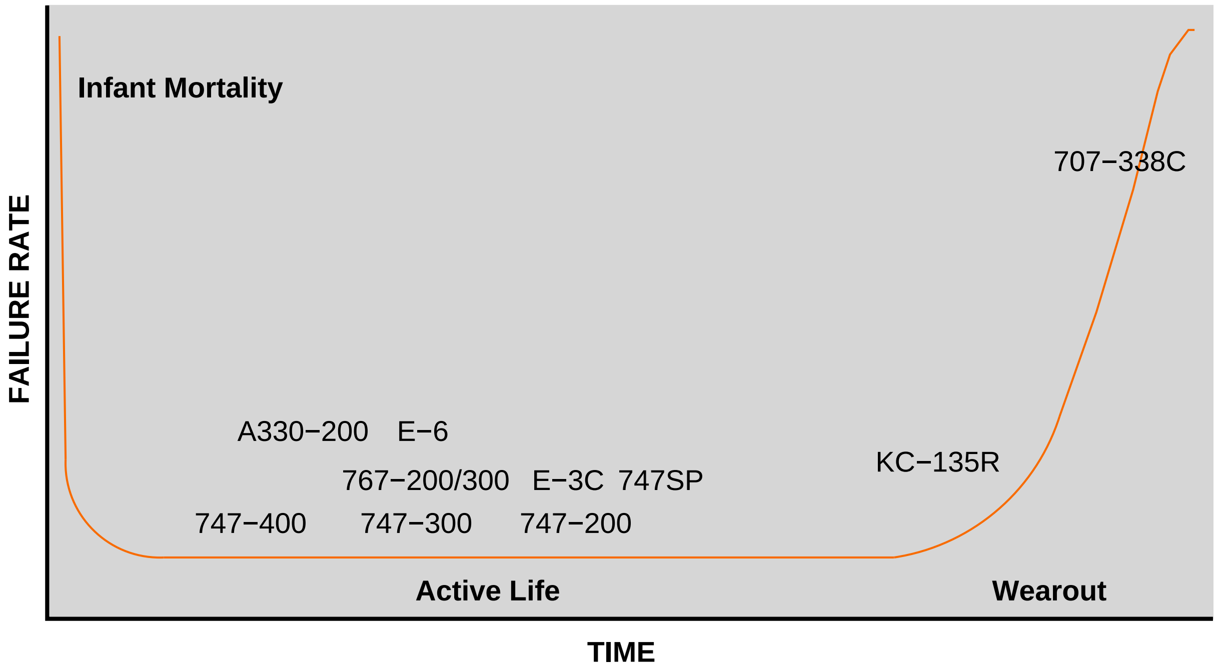

Figure 9: *Reliability theorists use the 'bathtub curve' to illustrate the failure rate behaviour of equipment. The 'infant mortality' period is associated with failures due to manufacturing defects, the 'active life' period covers time when the equipment can be economically used, while the 'wearout' period is when fatigue and corrosion introduce an increasing frequency of failures. For tanker conversions, the optimum is to select airframes which are likely to remain in production for as long as possible, yet are mature enough for affordable 7-12 year old used aircraft to be bought (Author).*

Minimising the cost of a tanker fleet over its life thus drives a buyer in the direction of those airliner types which are most widely used and most likely to thus remain supportable cheaply over the longer term. Further cost reductions will also accrue from the opportunity to share training facilities and exploit reservists flying commercial models of the same aircraft.

In this context, heavy tankers are a better buy than medium tankers, since typically half as many are required to deliver the same load of fuel, thus reducing support costs and aircrew numbers. Medium tankers look better only in the training role, and low intensity operations, where their lower fuel burn reduces operating costs.

Figure 10: *The Boeing (MDC) KC-10A is based on the DC-10-30CF airframe, which was superceded by the MD-11. With the recent completion of MD-11 production, the supportability of the US Air Force's 59 strong KC-10A fleet will be compromised once most of the commercial DC-10-30 fleet is retired in the 2010-2015 period, if not earlier due to the airline industry collapse (US Air Force).*

The principal cost driver in a tanker conversion is the Non Recurring Expenditure (NRE) incurred in the design, prototyping and flight testing of a conversion. For a small number of tankers, this overhead can rival the cost of the fleet. Therefore, the only economically viable choices for the ADF are established tanker conversions, where the manufacturer or another air force has absorbed the overhead.

At this time there are few such conversions in the market. Other than refurbished US Air Force KC-135Rs, the only tested and flown choices are the Boeing 707, Boeing DC-10 and Boeing 747. The Boeing 767-200 was chosen late in 2001 as a replacement for the US Air Force's oldest KC-135E tankers and will be engineered and flight tested over the next two years - Italy and Japan have committed to this type. The Airbus A310/A330 have been vigorously marketed, to date no conversions have been performed as the manufacturer seeks customers which are prepared to absorb the NRE of a conversion design, prototyping and test.

The only medium tankers which will incur zero NRE are the KC-135R and the Boeing 767-200, the former rebuilt from mothballed KC-135A tankers held by the US Air Force in their desert boneyard. While the Airbus A330 would be a viable alternative with ample numbers appearing in the used aircraft market in coming years, until another party pays for the NRE of the tanker conversion it would be quite expensive. The KC-135R is an excellent choice in terms of performance, but the basic airframes are very old and thus problems similar to those seen in the RAAF 707-338C may need to be addressed in the medium to long term.

In terms of heavy tankers, only the Boeing 747 and DC-10/MD-11 incur negligible NRE. The latter is not flown in Australia and is thus not viable, by default. The 747 is abundant and cheap in the used aircraft market, with older -200 and -300 series models similar or lower in cost to the much smaller 767 series. Boeing recently delivered the first 747-300SF freighter rebuild. With the impending production of the Longer Range 747-400 (previously 747-400X), 747X and possible production of the stretched 747X, extended range 777 and Airbus A380 series, we can expect to see the 747-400 soon appear in the used market at affordable unit prices as it is displaced from its most competitive niche. The 747-400 provides much better performance than the -200 and -300 models.

Cost and support factors aside, another important issue is performance. Jet airliner/tanker airframes can be broadly divided into two categories, by wing aerodynamic design.

These are airframes with 'fast' wings, with quarter chord sweep angles between 35 and 37.5 degrees, optimised for fast cruise at Mach 0.84-0.86, and airframes with 'slow' wings, with quarter chord sweep angles between 27 and 31 degrees, optimised for slow cruise at Mach 0.79-0.82. The 747, DC-10/KC-10, 707 and KC-135 fall into the fast category, the 767 and Airbus types the slow category.

A tanker with a slow wing does best when loitering in an refuelling orbit, as fuel burn is minimised, but is slower in transit to station and cannot keep up with fighters on long range deployment or strike sorties. A tanker with a fast wing can match the cruise climb profiles of fighters in transit and long range sorties, but burns slightly more fuel when parked in an orbit. So the tactical and operational advantages largely go to tankers with fast wing designs, accepting that in loiter intensive situations the aircraft is slightly less efficient than a slow winged tanker.

What the optimal choices in this game?

1. Tankers with fast wing designs are operationally superior, with some penalty to be paid in fuel burn.
2. New build airframes may not pay for themselves within a supportable aircraft life, given the slow rate of fatigue accrual.
3. A High/Low mix of medium and heavy tankers falls in between the operational economic advantages of a heavy tanker fleet and flexibility and training cost advantages of a medium tanker fleet.
4. A High/Low mix of medium and heavy tankers with a bias to heavy tankers is cheaper in offload per total dollar than a mix biased to medium tankers.

5. Established tanker conversions are much cheaper to acquire and support than new design conversions.

Where does this leave the RAAF? If the aim is to robustly address the White Paper capability goals, then some High/Low mix of aircraft using established conversions and fast wing airframes yields the optimum package, with the exact mix ratio yet to be determined.

Of course, if other criteria are placed above these, then other answers might fit. However, such a strategy either increases total package cost or compromises operational capability.

The optimal strategy for the RAAF is to aim for some High-Low mix of medium and heavy tankers, as this provides an appropriate balance between the flexibility, training and low intensity operational use economies of a medium tanker, against the crewing and high intensity operational use economies of a heavy tanker. Fiscal realities will however most likely force the RAAF in the direction of a single type tanker fleet, which makes careful choices all the more important. In a single type fleet, crewing requirements for a full fleet strength strongly favour heavy tankers. The RAAF was at the time of writing uncommitted to a specific tanker fleet model.

In terms of candidate airframes for the heavy tanker role, the short and medium term optimum is a 747 derivative, with an MD-11 derivative in the required offload class but presenting some longer term support issues. Used 747s are cheap and plentiful, indeed quite a few older Qantas -200s, -300s and SPs may become soon available.

The RAAF is presented with a difficult challenge in the selection of a new tanker aircraft. The Boeing 767-200, now to be flown by the US Air Force, will offer irresistable attractions in having access to the US Air Force support base and training base, as well as important production economies resulting from the US Air Force build of the aircraft. This is not the case for any other alternative even if the aircraft has been previously subjected to a tanker conversion. Inevitably, selection of the Boeing 767-200 as the RAAF's new tanker would present the issue of crewing a full strength tanker fleet at some future date - around 20 Boeing 767-200 tankers would be required to robustly support the RAAF's fighter fleet.

6.1 Boeing 707-338C

While the new White Paper commits the RAAF to 'new technology tankers', it is worth examining the 707-338C to place this decision into its proper context. The RAAF's existing fleet of four 707-338C tankers was intended to provide a training and limited operational capability. These aircraft were converted to tankers during the early nineties, by IAI/HdH in Melbourne.

The AAR hardware installation is based upon a design produced by the Bedek Division of Israel Aircraft Industries for the Israeli Defence Force, which has several tanker aircraft in service. The system design had some detail changes to meet the RAAF's engineering requirements. Most of the hardware was sourced in the US and UK, with remaining components supplied as upgrade kits by IAI. The Mk.32B refuelling pods were manufactured and supplied by Flight Refuelling Ltd in the UK.

Internal modifications to the 707-338C systems were necessary. The AAR system uses hydraulically powered fuel pumps to drive fuel to the pods, which in turn feed the fuel via hose to the receiver aircraft. Four submerged J.C.Carter fuel pumps are situated in the centresection fuel tank and these feed fuel into 3" pipes via a crossfeed valve arrangement which allows either pod to be fed by any pump. This functional redundancy was adopted to minimise the likelihood of fuel pump failure interrupting an AAR hookup. Under operational conditions each pod will be supplied by a selected pump. The 3" pipes are installed through the wing main spar box using attachments designed to decouple mechanical loads from the wing structure. The pipes then attach to mounting flanges within the wingtip pylons, the pylons are structurally attached to the forward and aft main spars.

The fuel management strategy used during AAR operations differs from that adopted for regular 707-338C operation, as fuel from the inboard and outboard wing tanks is pumped into the centresection tank from where it is offloaded to receiver aircraft.

Hydraulic fluid for the pumps is supplied via 1.25" pipes and hoses from two redundant utility hydraulic systems, designated UT1 and UT2. UT1 is the basic 707-338C hydraulic system which is powered by two Abex engine accessory drive hydraulic pumps fitted to inboard engines #2 and #3. Typically one fuel pump will be driven by UT1, together with remaining aircraft systems such as flight controls. UT2 is a new installation carried out as part of the upgrade and involves, other than the necessary plumbing, the installation of another two Abex hydraulic pumps on outboard engines #1 and #4. Again, under operational conditions, UT2 will in turn supply the second pod. This highly redundant strategy is designed to allow system operation with full or partial capability in the event of hydraulic or fuel pump failures. The system is designed to accommodate a boom or a third hose/drogue system.

The upgrade also incorporated dual redundant Litton LN-92 ring laser gyro equipment, dual redundant Collins SIT-421 IFF transponders, and a forward facing Hazeltine AN/APX-76B(V) IFF interrogator with dipoles mounted on the existing weather radar antenna. A Collins 150 Tacan system was installed, consisting of AN/ARN-118 and APN-139 subsystems which allow receiver aircraft to locate and rendezvous with the tanker. Additional communications equipment included a Magnavox AN/ARC-164 UHF transceiver and a Collins DF-301E/F UHF DF set. The refuelling operator was provided with a steerable camera in a lower fuselage turret.

The aircraft do not have lower deck auxiliary fuel cells, since at 158,000 lb of internal fuel, the sixties technology JT3D-3B engines would be unable to get the aircraft airborne from most runways with the additional weight of fuel.

In terms of basic airframe aerodynamic performance, the 707-338C is without doubt the best medium tanker in existence. Indeed, the never implemented KC-135H and KC-135X upgrades would have seen the 707-320B wing retrofitted, with either TF-33 or CFM56 engines, to KC-135A airframes. The 707-320B is the basis of the E-3 AWACS, E-6A TACAMO, E-8 JSTARS and KE-3A tanker.

The RAAF's 707-338Cs have little remaining fatigue life, with serious fatigue problems in key structural components of the wings and centresection. Moreover, other problems have arisen. The JT3D-3B engines, which are too noisy for most civilian airfields and underpowered, are now being obsoleted by the manufacturer. Old age is also taking its toll, with corrosion in some places and the electrical wiring approaching the end of its safe life. It is likely that the 'steamgauge' cockpit instrumentation will be become harder to support over time, as the US Air Force puts Pacer CRAG glass cockpits into its 707 and KC-135 derivative fleet.

Replacing the engines is not a difficult task, the candidates being either the CFM56 common to the 737 and KC-135R, or the JT8D-219 common to the MD-80 series. Both engines deliver similar 21,000 lb class takeoff thrust, with the CFM56 offering slightly better SFC due to its much higher bypass ratio, while using a bulkier and less convenient nacelle size. While the CFM56 is the better performer, a retrofit is costlier due to the need for structural work to fit a very different pylon design. An engine replacement would come to around USD 30M per aircraft. Replacing the electrical wiring is also straightforward, but potentially costing several million per aircraft, as the wiring is embedded in the structure in many places and difficult to access.

The biggest long term issue for the 707 will be corrosion. The US Air Force greatly regretted its decision to accept a political directive to use refurbished 707-320B airframes for the E-8 JSTARS, instead of new build 707-320/E-3/E-6 airframes. Repair of all airframe corrosion pushed the price of the E-8 refurbishment close to that of new build airframes.

The JSTARS program yielded a large database of corrosion statistics on the 707 airframe. The most severe corrosion was generally found in four hot spots, the worst by far being around the nosewheel well and forward fuselage. Other problem areas were in the lower fuselage, at three points aligned with the leading edge of the wing, and ahead and behind the main undercarriage wells. Lesser but still significant corrosion was found in the wings, especially around the engines, and upper wing roots. These corrosion hot spots differ from those seen in the RAAF fleet, which has experienced most of its corrosion in the upper wing skins, fuselage roof and tail surfaces.

Herein lies the crux of the issue, in that the reskinning, structural repairs and rewiring required to give the 707s another 20 or more years of airframe life could prove to be as expensive as USD 65M per aircraft, pushing the price close to that of a very good used 747, 767 or Airbus.

Add in engines, a boom, avionics updates and the cost becomes very close to a 747, 767 or Airbus conversion.

In a sense this is unfortunate, since the 707 is aerodynamically a superb fast tanker, especially if fitted with new engines, a boom and lower deck fuel cells, indeed it would be much like the proposed KC-135H.

6.2 Boeing KC-135E/R/T

Boeing built 820 KC-135A and derivative special purpose airframes between 1957 and 1965. No less than 732 were KC-135As. At this time the US Air Force has 609 KC-135s of various models in service with US Air Force, AFRes and ANG squadrons, and around 60 airframes of various subtypes remain at the AMARC boneyard. It remains the most numerous large aircraft in the US inventory.

The KC-135 is the forerunner to the 720/707 series, using a single lobe fuselage which is several inches narrower and less tall than the 707, and wing very similar to the now extinct 720/707-100 series. Up to 31,200 USG of fuel is carried in 12 wing tanks and nine fuselage tanks, only one of which is above the floor.

The aircraft have been through extensive upgrades over their service life. Known structural fatigue problems were addressed by a number of modifications. The WS360 fix alleviated a problem in a wing splice plate, ECP 405 replaced 7178-T6 alloy lower skins between the engines with stronger 2024-T351 alloy skins, and replaced around 62% of wing structure, including many spars, rib cords and stiffeners. These modifications add 26,000 hrs to the structural fatigue life of the airframe.

An ongoing upgrade has seen the replacement of the immersed fuel pumps with a safe dry running type. A number of aircraft were retrofitted with yaw dampers cannibalised from retired 707s.

Two major upgrade programs are active at this time. The most significant of these are the KC-135R and KC-135T programs, which incorporate the replacement of the J57 turbojets with CFM56-2B1 (F108-CF-100) fans, the installation of a Flight Control Augmentation System (FCAS) incorporating a yaw damper and improved pitch trim control, the addition of a pair of T-62T-40 auxiliary power units (APU) in the rear fuselage for unassisted ground starting, improved brakes and electrical power generation, strengthened undercarriage, aft fuselage blister windows, a refuelling receptacle above and behind the cockpit, and the new technology improved refuelling boom using an extruded tube structure.

The original CFM56-2B1 had the thrust reversers removed, and the retrofit requires struc-

Figure 11: *The US Air Force KC-135 remains the most numerous and capable medium tanker in operational service at this time, with no less than 609 in US Air Force, AFRes and ANG service. Subjected to numerous structural upgrades, the aircraft has a projected structural fatigue life until 2040. At this time the US Air Force is more concerned about corrosion and long term support of the unique system components. The current KC-135R and T models (Upper) are produced by refurbishing and modifying the basic KC-135A model, of which around 60 aircraft remain in the AMARC boneyard. The KC-135E (Lower), here depicted refuelling an F-22A, will be replaced by the Boeing 767-200 (US Air Force).*

tural strengthening of the front wing spar, new pylons and unique nacelles. The engine has a static rating of 4,970/22,000 lbf and cruise SFC of 0.662 lb/lb/h (cf JT8D-219 at 5,250/21,700/0.737).

The other important upgrade is Pacer CRAG, which fits a modern technology glass cockpit, flight management system and GPS, intended to remove the need for the navigator. In practice, high workload sorties may still require a third flight crew member.

An optional upgrade applied to a small number of US Air Force KC-135Rs, is the Boeing Multi-Point Refuelling system, essentially an wingtip installation of Mk.32B pods similar to that in the RAAF 707s.

The ANG KC-135E upgrade involved the retrofit of TF-33-PW-102/JT8D-3 fans, in part cannibalised from retired 707s. Many ANG units are now receiving KC-135Rs.

The KC-135R is the best medium tanker available in the market at this time, in terms of capabilities and performance, and the nearest equivalent would be a 707-320 series with a similar package of upgrades applied to it.

The cost of a KC-135R is nominally around USD 53M or slightly more with the Mk.32B pods and Pacer CRAG fitted, while the KC-135E is nominally worth USD 30.6M, and the KC-135A nominally USD 26.1M. Therefore the cost of raw boneyard KC-135A is similar to that of a pre-loved 747-200 series.

The big issue for the US Air Force is affordably stretching the life of the fleet to its expected fatigue life expiry in 2040. As the airframes are of similar age to the RAAF 707-338C and US Air Force 707-320B JSTARS, the US Air Force has major concerns about corrosion and other deleterious effects of old age on the airframe and systems. While the US Air Force has plans for a new technology KC-X tanker to be fielded after 2013, the cost of replacing around 600 KC-135s with even a lesser number of new KC-X tankers makes any life extension effort on the KC-135 highly profitable. Even should an affordable long term fix to the corrosion problem be found, long term support will be hampered by poor availability of other system and airframe components. We may yet see the KC-X program initiated earlier than previously planned, and many reports from the US suggest the program may be accelerated - the move to replace the KC-135E with the Boeing 767-200 may later be extended to become KC-X.

In considering the KC-135R as a medium tanker alternative for the RAAF, the principal issue will not be performance or capabilities both of which are excellent, but rather long term support costs, the same problem faced with the 707-338C. There would be a genuine risk that a KC-135R buy would soak up USD 50M per airframe of corrosion repair and refurbishing costs per unit, at some time during the next 2 decades. Current statements from the RAAF and DMO would indicate that the KC-135 will thus not be considered.

6.3 Boeing 747-400

The Boeing 747 family of aircraft is used both by Qantas in Australia, and Air New Zealand. Qantas flies it in passenger and freighter variants. The Boeing 747 design is a derivative of a sixties Boeing proposal for a military airlifter, which lost out to the Lockheed C-5A Galaxy. The aircraft was later evaluated against the DC-10 as part of the US Air Force Advanced Tanker / Cargo Aircraft program, losing out to the McDonnell Douglas KC-10A proposal despite its superior performance. Photographs exist of the 747 refuelling even the SR-71A during these trials.

Several AAR boom and receptacle equipped 747-100B tankers were supplied to Iran during the mid to late seventies, these including lower deck fuel tanks, and two US military variants exist, the E-4B and VC-25A, both with AAR refuelling receptacles.

The conversion package for Iran was performed with the expectation that other clients would be found, and a full production standard documentation package was generated as a result. Therefore a current retrofit of the basic KC-135 boom to the 747 incurs minimal Non Recurring Expenditure (NRE). The Iranian aircraft employed an operator with direct view as per the KC-135 design, but located behind a recessed rear fuselage window in the aft pressure bulkhead, rather than in a protruding fairing as used by the KC-135.

The ‘classic’ KC-135 boom was re-engineered during the nineties in a number of areas to employ current production techniques such as extrusion rather than riveting. Booms supplied on recently delivered KC-135R conversions have been based on this newer implementation which would be used in any new build 747 retrofit.

A cheaper alternative to produce, at the expense of some NRE, would be the remotely operated boom as used on the KDC-10-30CF and planned for the US Air Force 767-200 tanker, as this would avoid the structural work at the aft end of the fuselage pressure shell.

The lower deck volume of the -100/200/300 and -400 models available for container freight provides ample space for additional auxiliary fuel cells, which would be essential to extract the full offload potential of the aircraft as a tanker. Since intercontinental variants of the 747 carry a generous internal fuel load, at MTOW for most variants only about 20 to 40 tonnes would need to be carried in auxiliary lower deck fuel cells, with crossfeed from the main tank employed.

A typical implementation for a lower deck fuel cell would resemble a reduced height LD2 type freight container. Without potentially expensive structural reinforcement of the lower lobe floor, the auxiliary fuel cells are weight rather than volume limited. The aggregate gross weight limit for fore and aft lower lobe compartments is 47.7 tonnes, assuming an evenly distributed load, which bounds the available capacity of lower deck tanks. The US FAA requires the tanks

Figure 12: *The only choice in recently built heavy tankers will be derivatives of the 747-400, which offer superlative airlift capability and remain the fastest subsonic airliner type in the market. The US Air Force evaluated the 747 in the ATCA program during the late seventies, but selected the smaller KC-10A instead (Boeing).*

withstand loads of 9G. Typical contemporary implementation employs a rigid double walled tank design, rather than the older 'fuel bladder inside a metal box' style. A derivative of the auxiliary fuel tank design for the Longer Range 747-400 would be used.

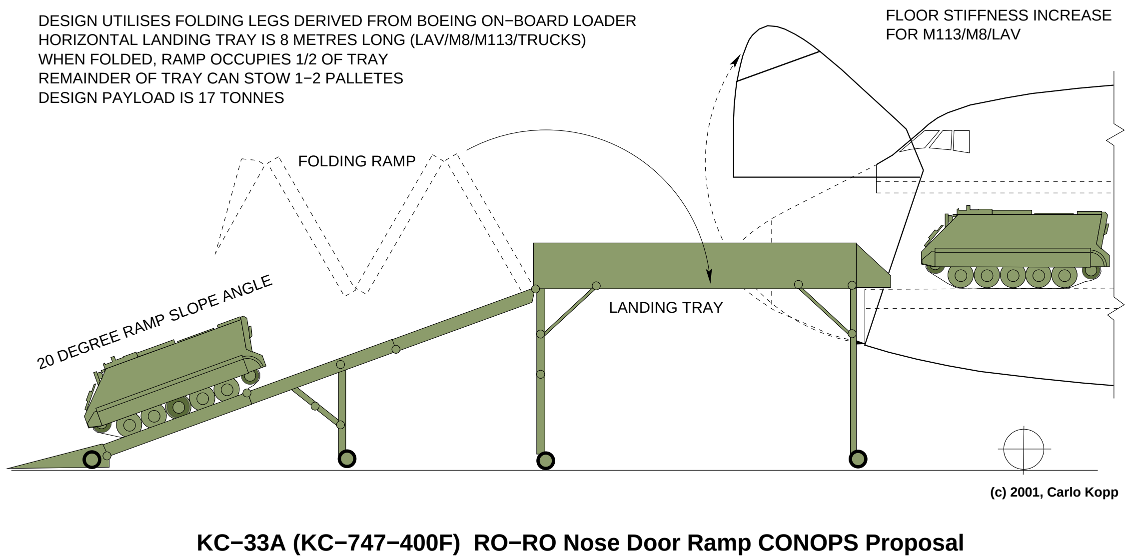

Figure 13: *Boeing 747-400 derivative tankers offer the greatest long haul airlift capability available in the market. The aircraft is competitive against the C-5 Galaxy airlifter but the payload size is limited typically to items transportable by the C-130. Depicted is a concept for an internally stowed Roll-On/Roll-Off loader derived from an existing Boeing internal loader (Author).*

Offload performance at a 1,900 NMI radius would be about 95 tonnes of fuel or better, for a Combi or Freighter configuration with lower deck auxiliary fuel cells. Such performance is superior to the US Air Force KC-10A.

US military 747-200B variants are designated C-25A, such as the VC-25A 'Air Force One'. The designation C-19A is reserved for 747-100 aircraft committed to the CRAF scheme. Therefore a 747-200B tanker/transport variant would be designated a 'KC-25A', with a different suffix applied for a different 747 variant. The proposed military airlift variant of the 747-400 was to be designated the C-33A, making a 747-400 tanker a 'KC-33A'.

A simple measure of the Boeing 747 against other established tankers is that it delivers offload performance potentially superior and payload-range superior to the KC-10A Extender, yet it is fast like the KC-135R or Boeing 707 tankers, cruising at 0.84-0.85 Mach.

Therefore this aircraft is the only type which satisfies the requirement of an existing domestic operator base, the requirement for an established boom equipped AAR conversion, and delivers the long range AAR offload performance and volumetric requirements needed for the strategic AAR and airlift roles, respectively.

Freighter conversions of the four basic versions are very widely used in the commercial air freight market, indeed the current industry trend is for older 747-100 and -200 airframes to be retrofitted into freighter configuration by the addition of a large aft fuselage Side Cargo Door (SCD), and installation of the freighter floor. Designated a 747 'Special Freighter' (747SF or 747-100SF/200SF), conversions are performed by Boeing Wichita, GATX-Airlog, Pemco Aeroplex, Israel Aircraft Industries and HAECO with costs depending on the scope of the conversion package. Typical costs are between USD 12M and 20M per airframe.

The 747-400 is the current production model, introduced in the early nineties, available in passenger, Combi and Freighter versions. It features the extended upper deck of the -300, and a new extended wing, fitted with winglets. Since it is available either new build, or with a service life under 10 years, fatigue life is not an issue for the 747-400 at this time.

The 747-400 offers the best load carrying performance of any 747 variant, but its larger MTOW imposes the need for better runways, and due to its large wingspan ground handling can be an issue on some sites.

Prior to the 11th September, the 747-400 was expensive in the used aircraft market, as it remained strongly in demand, with typical used aircraft worth between USD 92.5M and 158.5M. More recently, with the airline industry collapse the 747-400 is becoming more affordable and available.

A tanker/transport conversion would incur some NRE as structural changes to the airframe design introduced after the 747-200 would require re-certification and flight test of the revised design. A revised 747-400 conversion could benefit from the use of the fly-by-wire KC-10A/767-200 boom installation. To date no 747s have been equipped with 'hose and drogue' refueling pods.

The Engineering, Manufacturing and Development contract for adding wing-mounted 'hose and drogue' refueling pods to the KC-135R Stratotanker cost approximately USD 24.4M. The cost of conversion kits to fit Mk.32B pods to US Air Force KC-135R aircraft is about USD 2.55M per aircraft, excluding the cost of the pods. The cost for a KC-25/747 kit would be slightly higher due to the longer fuel lines required. Given that Boeing have performed the adaptation of both the KC-135R and KC-10A for wing mounted Mk.32B pods for the US Air Force, it is reasonable to assume that much of the design work could be directly adapted to a KC-25/747 design, thereby reducing the magnitude of the NRE required. The all up cost of equipping a dozen KC-25/747 aircraft with pods would be thus of the order of USD 50M, excluding the cost of 24 pods and appropriate spare components.

All Boeing 747 variants are available as freighters, thus providing a very significant strategic airlift capability. A simple measure of the Boeing 747-200CF/300CF/400F as an airlifter is that it provides payload range performance in the class of a US Air Force Lockheed C-5 Galaxy, but its freight loading door limits payload items to sizes similar to those carried by a C-130 Hercules or C-141 Starlifter. With the exception of length, the Boeing 747 SCD can handle items slightly larger than either the C-130 or C-141. Therefore any Army assets air portable by C-130 will almost certainly be portable by 747, thereby taking a significant load off the RAAF C-130 fleet[2].

6.4 Boeing 767-200 and Airbus MRTT/310/330

Both Boeing and Airbus have actively marketed tanker/transport derivatives of their widebody twins, as the Boeing 767-200 and MRTT respectively. Both types offer similar or better offload performance than the KC-135R (a Boeing 767-200 cca 15% better), and are also much better in the secondary airlift role due to larger internal volume and greater floor strength. In terms of simple metrics such as payload range, long range variants of both aircraft make for excellent medium tankers, at the higher end of the performance scale. With a large support base worldwide in commercial use and large numbers of used airframes, albeit a little expensive at this time, both would be relatively easy to acquire and support.

The difficulty with the Airbus MRTT-310/330 derivative is that nobody has yet paid for the design, prototyping and flight test of the conversion, which is likely to run into a considerable sum. Flight test against large numbers of inventory military types to be refuelled can be particularly resource hungry. Until this overhead is paid for either by the manufacturers or another air force, this cost overhead would make both types an expensive proposition for an RAAF fleet.

The Boeing 767-200 is likely to become the standard US Air Force medium tanker, progressively replacing all of the Cold War era KC-135 variants in service, but also providing the baseline airframe for the new 'MC2A' aircraft which will replace the E-8 JSTARS and E-3 AWACS surveillance aircraft. Prior to the events of the 11th September, a used 767-300ER cost between USD 50-90M per unit, pushing the cost with an refuelling conversion close to the USD 70M-110M mark, without the overhead of conversion design, prototyping and flight test.

An A330-200/300 derivative would offer slightly better offload performance than an equivalent 767-200, and pod installation on the wings is simplified by structural commonality with the A340. However, the smaller operating base will push the unit cost up. As recently announced, Qantas intend to operate seven A330-200 and six A330-300. The key issue for the A330 will be the cost of used airframes, even the oldest of which can fetch around USD 90M per unit.

[2] Refer RAAF APSC Working Paper No.82 'A Strategic Tanker/Transport Force for the ADF' refer http://www.defence.gov.au/aerospacecentre/publish/paper82.htm.

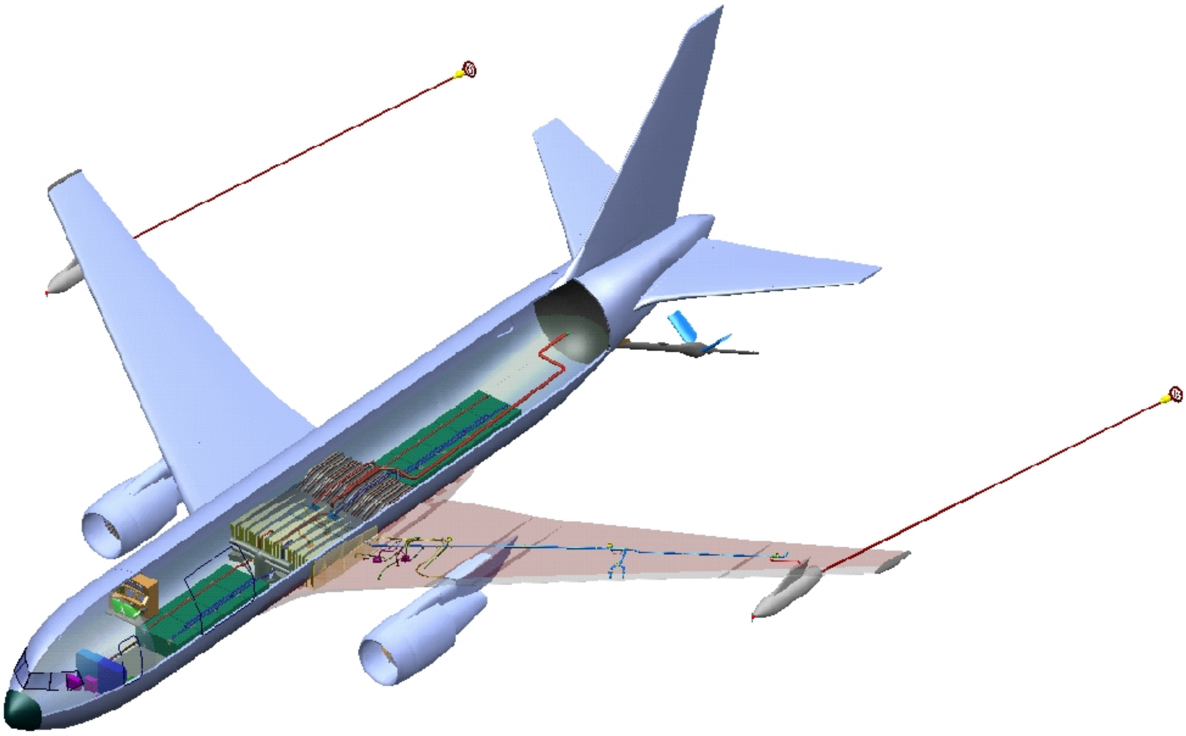

Figure 14: *A Boeing 767-200 is a credible 'one-for-one' replacement for the KC-135R and 707-338C, offering better offload and airlift capabilities, but it is slower using a medium haul optimised wing, making it less convenient in situations where dash speed and long range fighter support are needed. It has recently been selected by the US Air Force as a replacement aircraft for the obsolescent KC-135E, while also being selected by Italy and Japan for their aerial refuelling requirements (Boeing).*

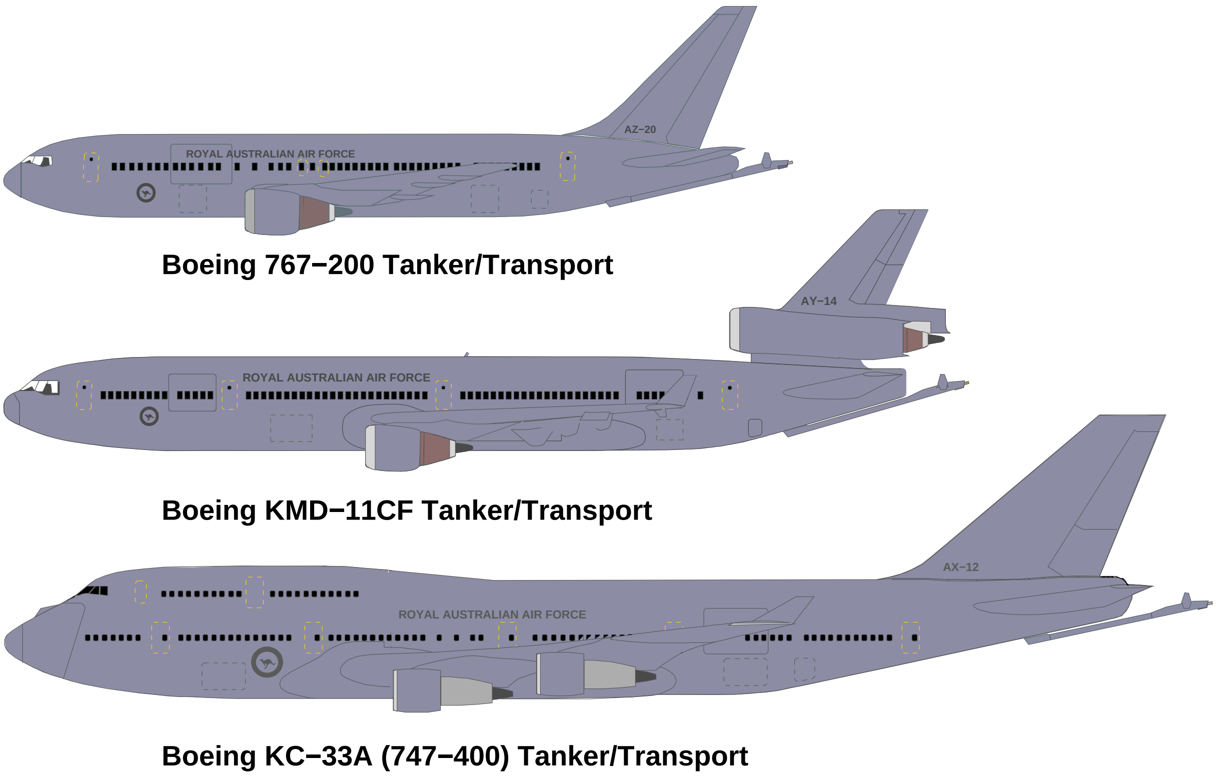

Figure 15: *Size comparison of the Boeing 767-200, KMD-11 and 747-400 series tanker/transports (Author).*

Italy and Japan, following the US Air Force lead, chose the Boeing 767-200 over an Airbus MRTT-A330 derivative for their respective tanker requirements.

The limitation of both the Boeing 767-200 and MRTT-A310/A330 is the Mach 0.78-0.82 optimised wing, which is a byproduct of the original domestic medium haul design optimisation of both types. This is especially an issue for the Airbus designs, and makes both families of aircraft less than ideal for military use where transit and dash speed is an issue, such as supporting reactive long range CAPs and maritime or long range strike sorties, or emergency refuelling.

Another key issue for both of these twin engine airframes is mission reliability on long duration or long range over-water sorties. While the loss of an engine does not mean the the loss of the tanker, which can straggle home on one engine, it would most likely result in a 'mission abort' since the aircraft could not be expected to continue its refuelling mission on one engine alone. The practical consequence of this is that more airborne spare tankers will be required to ensure that a tanker abort does not result in a complete strike package or CAP mission abort. With the White Paper capping the ADF fleet to 5 tankers, this would significantly complicate what the RAAF could do with a medium tanker based fleet.

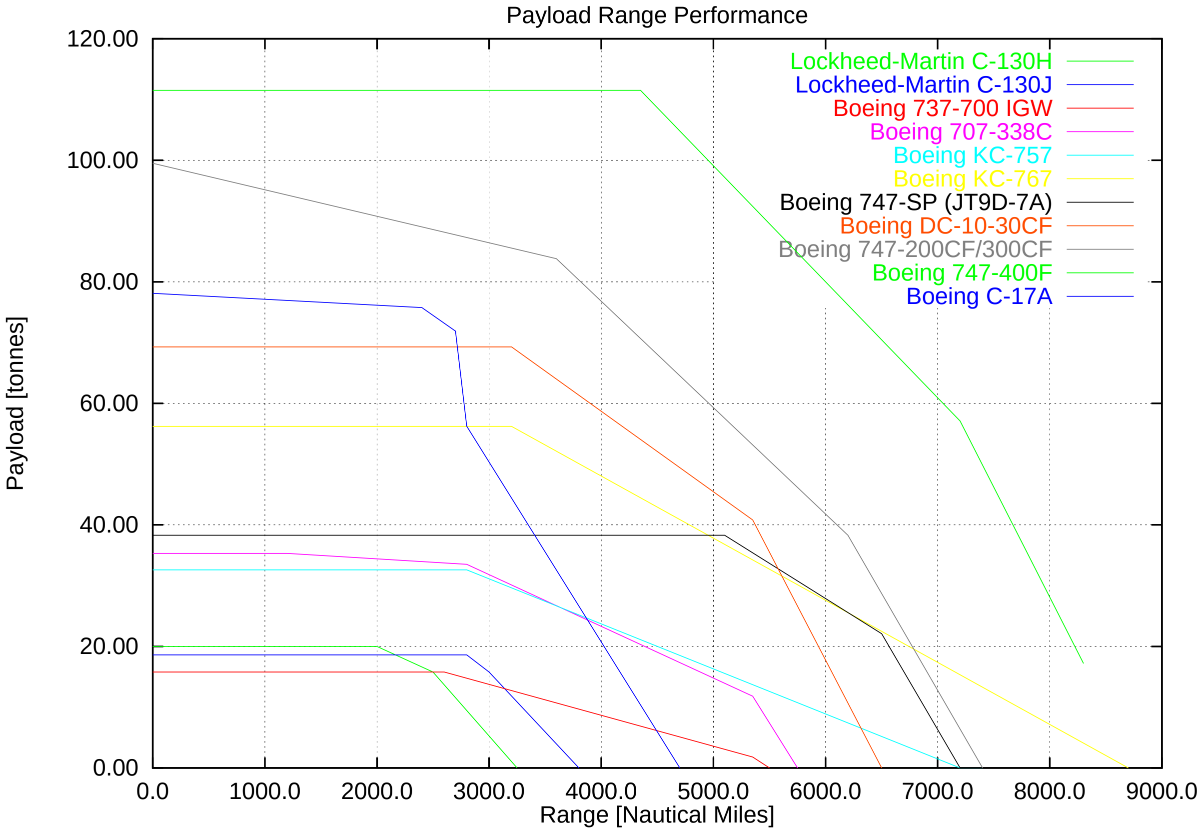

Figure 16: *Comparison of payload/radius performance for representative aerial refuelling aircraft (Author, Boeing and other data).*

Therefore, should the RAAF opt for either family of aircraft to replace the 707-338C as the standard medium tanker, the aircraft will be relatively expensive in offload per dollar due to their size, and tactics will need to be adapted to accommodate the dash speed performance limitations of these types, and the limitations of two engines over water.

7 Airlifters as Tankers

An alternative which is frequently raised in the public debate on aerial refuelling is the use of airlifters such as the C-130 Hercules, C-17 or A400M as tankers, by equipping these with refuelling equipment. Airlifters are a poor choice for aerial refuelling, since they cruise at much lower speeds than fighters, and cannot compete against airliners in fuel offload performance, the principal measure of a tanker's worth. Moreover, if committed to refuelling they are unavailable for airlift, and vice versa.

To place this in perspective, a C-130 Hercules airlifter equipped as a tanker delivers about 1/3 the offload performance of a medium tanker like a 707 or KC-135. Other than niche roles such as refuelling helicopters or close air-support fighters, the C-130 is not very useful as a tanker.

It follows that the RAAF would have to commit its whole airlift fleet to aerial refuelling operations to achieve the effect of a small number of genuine tankers, imposing thus much greater demands in aircrew and airframe time per tonne of fuel offloaded.

The other side of this argument is that a robust fleet of RAAF tanker/transports can address much of the strategic airlift needs, thus freeing up the C-130 fleet almost wholly for tactical Army support work.

8 Electronic Warfare Self Protection Suites

At this time US Air Force tankers do not carry either Radar Warning Receivers (RWR) or Defensive Electronic CounterMeasures (DECM)/Expendables. Therefore these aircraft are wholly dependent upon defence by fighters and supporting AWACS.

This remains a very contentious issue in the US. In every air war since the 1960s, tankers have had to perform emergency refuelling penetrations of contested airspace to rescue fighters with empty tanks, most recently during Allied Force. Without RWR/DECM, these aircraft are sitting ducks for long range mobile Surface to Air Missiles or fighters which may penetrate the defensive CAPs. Some years ago the author discussed this issue with a US Air National Guard tanker captain who flew in Desert Storm. Their operational practice was to carry extra crew to maintain a lookout using binoculars!

The ongoing debate is likely to be intensified with recent statements by US Air Force Chief of Staff Gen John P. Jumper, who is seeking ‘smart tankers’ equipped with Electronic Support Measures (ESM) receivers to supplement existing electronic intelligence and survillance capabilities in the E-3 AWACS and RC-135 Rivet Joint. Many ESM receivers incorporate a threat warning display in the cockpit.

With the impending deployment of 80 NMI range ramjet Beyond Visual Range Air to Air Missiles such as the Russian Vympel R-77M RVV-PD (ramjet AA-12 Adder), the safety margins for forward operating tankers have been significantly eroded. US operational experience clearly shows that fuel management by fighter pilots in the heat of combat will always be an problem issue, so tankers will always be confronted with the need to either skirt or penetrate into dangerous airspace.

The inevitable conclusion is that a prudent operator will install some defensive EW capability.

What represents the best EW package is an excellent question. An RWR is a must, preferably one with decent detection range performance against a 10-20 kW class air intercept radar. A towed decoy package would be an excellent defensive measure against long range radar guided Air to Air Missiles and Surface to Air Missiles. Whether expendables are justified is open to debate, insofar as a fighter getting close enough to use a heatseeking Air to Air Missile might just as well use his gun. At the speeds, altitudes and ranges tankers will be operating at, the primary threats will remain long range Surface to Air Missiles like the SA-10/12/20 and Beyond Visual Range missile shots by fighters.

If the tanker has a secondary role as an airlifter, then shoulder launched Surface to Air Missiles do become an issue and a flare dispenser or infrared jammer is justified.

Equipping a tanker with a robust defensive package is a large cost overhead, which could fall into the USD 5-20M cost range, depending upon how elaborate the package needs to be. Should the RAAF consider equipping its future tanker fleet with a defensive package, there would be much merit in using as much common hardware as is possible against the F-111 and F/A-18. Should the domestic ALR-2002 series be used, this would at least introduce some economies of scale into the equation. Given the airframe size of a tanker, antenna and towed decoy placement is not an issue.

9 Funding Tanker Fleet Expansion

As always, funding expansion of an existing capability will result inevitably in arguments over money. The basic cost of a robustly sized tanker fleet would vary significantly with the mix of aircraft chosen and level of capability per aircraft. For instance in heavy tankers, provision of full freight capability can add USD 12M-20M per aircraft. While plumbing and wiring for wing pods costs around USD 2.5M-3M per aircraft, an all up tanking package including a boom, manifold and pump system, auxiliary tanks, AAR receptacle/probe and single point ground refuelling falls into the USD 30M-35M range. Additional avionics such as JTIDS/MIDS terminals, secure military comms, military GPS and a minimal RWR would run into millions per aircraft. Depending on the type and age of the airframe chosen, between USD 30M and 90M could be spent. Therefore a medium or heavy tanker could cost between USD 75M and 145M, medium tankers not necessarily being cheaper to buy than heavies. With fleet numbers between 12 and 28 the total package cost could vary between USD 0.7B and 4B, depending on choices made. Therefore doing a proper tanker fleet expansion would be a large project, albeit much smaller than AIR 6000 and at most similar to AIR 5077 in costs.

There are numerous ways in which this could be implemented. The ‘classical’ model would be to order the aircraft to be delivered over a 3-5 year period, and expend around USD 0.5B annually over that period. Alternately, the buy could be spread over a 10 year period, halving the annual cost to about USD 250M and also providing plenty of time to build up aircrew and training systems.

Another strategy is private financing (PFI), where the Commonwealth would contract a supplier such as an airline to provide the aircraft and crews on demand, either for the whole tanker fleet or a portion of it. Numerous alternatives exist in PFI schemes, ranging from a dedicated RAAF use only tanker fleet, to 'dual use' aircraft which are swapped between military tanking and commercial transport work.

In a 'dual use' PFI arrangement, the aircraft would be owned by the contractor, and flown as commercial freighters or airliners, with pods, military comms and EW equipment removed, but retaining the tanker plumbing, wiring, pylons and boom. The performance hit resulting from the extra weight/drag would be offset in the cost of the contract. Regular training, large exercises and crisis situations would see some or all of the 'dual use' PFI aircraft withdrawn from commercial use and reconfigured for RAAF operations.

The PFI model is attractive to Australia's political leadership since it spreads the cost of the fleet over time, and does not incur the large budgetary 'hit' of a single large purchase. Whether it would be cheaper overall than doing it the 'classical' way remains to be determined. Indeed, some very complex contractual arrangements may be required to keep both parties happy, especially with a 'dual use' PFI model. The risk is that poor choices either by contractor or Commonwealth could land either with a large long term contract which doesn't work for them in the intended manner, resulting in litigation and profit destroying disputes.

Crewing a 'dual use' PFI fleet raises other issues. While commercial pilots may be viable for training operations, crisis or wartime use would demand reservists.

Other complexities may also arise with 'dual use' PFI schemes, such as aircraft in commercial use overseas being impounded by allies of an opponent should a dispute arise. The withdrawal of the aircraft from commercial service for mobilisation would be a dead giveaway of military intent, and the time and cost overhead of reconfiguring them for military use would make any fleet mobilisation an expensive proposition.

Most of these complexities vanish with a dedicated military PFI fleet, which in effect becomes a form of a wet lease arrangement (the US Air Force will operate the new Boeing 767-200 tankers under commercial hire-purchase leasing arrangement). Such arrangements are potentially much simpler, but do not offer the political attractions of commercial work to offset costs.

While a PFI fleet may have the potential to ease or remove the funding crunch of an upfront buy, it does introduce numerous complexities which need to carefully considered.

10 Conclusions

Tankers are the backbone of a modern air force, and by this measure the RAAF is at this time in a very weak position. More tankers are essential to put genuine credibility into the RAAF's force structure, and meet the stated capability goals in the new White Paper.

Without a robustly sized tanker fleet, the RAAF would be unable to perform medium and high intensity air defence operations in the 'cruise missile launch belt' north-east of the Pilbara and Timor Sea, and would be hard pressed to effectively escort the F-111 to the outer bounds of its combat radius. Indeed, genuine independent air operations over the air sea gap are contingent upon having a proper number of tankers. The order of magnitude in tanker numbers is at least 12.5 heavy tankers, 20-30 medium tankers, or some High/Low mix of either.

In terms of medium tanker choices, genuinely cheap options do not exist in the foreseeable future - although in the near term the post 11th September airline industry collapse will see a transient reduction in the market cost of used airliners. Many longer term alternatives are in some respects inferior performers to established tankers such as the KC-135R and 707-338C, both of which would need over the longer term very expensive rejuvenation. In heavy tankers, the 747 remains the most practical and cheapest choice, with the KMD-11 an alternative. Capital acquisition unit costs to a government or a private contractor would be of the order of USD 2B for a 50/50 medium/heavy mix and comprehensive equipment fit.

The biggest issue for the RAAF in tanker fleet expansion will be crewing, even with the most aircrew efficient choice of heavy tankers. Another issue will be the provision of adequate fuel replenishment to northern bases. A 747 rated runway close to Karratha and its planned synthetic fuel plant could prove to be a very useful asset in this respect.

None of these problems are insurmountable, nor unreasonably expensive should the government make judicious long term choices. Nevertheless, they will present challenges within a broader Canberra institutional culture which has a very poor literacy level in these issues and is very uncomfortable about short term expenditure.