# Chapter 13

# MILITARY PLATFORM EFFICIENCY MODEL

## 1. Summary

In this outside-in analysis, we synthesize past work and new data on military platforms to assess potentials for efficiency improvements. We rely on baseline assumptions from the Energy Information Administration's *Annual Energy Outlook* (*AEO*) *2004* to describe the efficiency potential through different technology packages. It appears that readily available technologies could, if fully implemented, save about 2/3 of direct *platform* fuel. This does not count substantial fuel savings from avoided lift fuel to deliver metal and fuel. As illustrated in Figure 13-1, the fully implemented platform-specific direct-fuel savings are distributed as roughly 68% Air Force, 64% Navy, and 78% Army. These percentages will change and the total savings will increase because of avoided lift of metal and fuel (and the second-order effect of avoided fuel to deliver that lift fuel). However, it is not possible to determine the total potential percentage saving or its inter-Service allocation, as we were not able to locate data on which Services use how much lift fuel to deliver their own or other Services' assets into theater and then re-extract them.

## 2. Introduction

Military energy consumption as measured by Energy Information Administration (EIA) for 2000 was 0.587 quad. Our baseline bottom-up calculation of military fuel consumption from platform specific data from 1999 and 1998 sums to 0.565 quad[1], within 4 percent of the EIA data. However, the platform data does not include building energy consumption as the EIA data does. EIA projection for energy use by the military increases 40 percent from 2000 to 2025[2]. We have assumed that this increase does not include improvements in platform efficiency and have only applied this increase as if it were a uniform increase in demand for all military services (i.e., transport, refueling, reconnaissance, air strikes, patrol, etc.). Thus, all efficiency measures suggested in this analysis are subtracted from a baseline energy consumption of 1.4 times 1998–1999 consumption.

For each service (Air Force, Navy/Marine Aircraft, Navy Ships, and Army) platforms representing 85–95 percent of total fuel consumption are individually modeled. The savings from these samples are scaled as if the remaining platforms, representing 5–15 percent of total consumption, were to experience the same aggregate improvement.

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[1] Supplied by Tom Morehouse (Institute for Defense Analysis).
[2] Energy Information Administration, *Annual Energy Outlook 2004,* DOE/EIA-0383. Washington, DC: EIA (January), www.eia.doe.gov/aeo/.

The model considers two types of deployment schemes: Complete Deployment and Plausible Deployment. Complete Deployment assumes all current military platforms are replaced with new designs. Plausible Deployment refers to military fleets composed of a mixture of legacy platforms and new design based upon estimates from research of projected replacement dates and rates of deployment for each platform. In this scenario retrofit efficiency measures are applied to all legacy platforms and new designs represent integrated application of all efficiency measures proposed. The model also considers two classes of efficiency improvements: *Conventional Wisdom (CW)* and *State of the Art (SOA)*, each of which are described in detail in Tables 13-6 and 13-7 at the end of this *Annex*. For example, for new Air Force transport aircraft, *CW* applies 787-similar airframe improvements while *SOA* applies even more advanced Blended-Wing-Body (BWB) improvements. The different combinations of deployment schemes and classes of efficiency measures yield the four different scenarios considered in this model as seen in Figure 13-1.

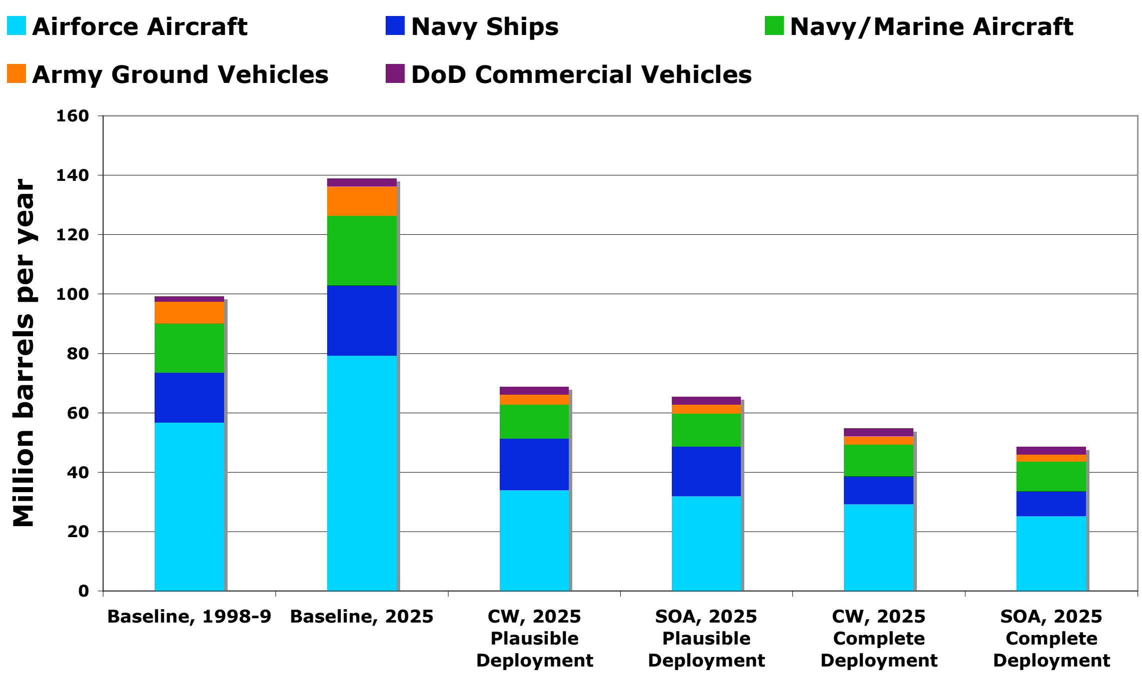


***Figure 13-1:*** *Military petroleum consumption historic and projected. Complete deployment is the technical potential for oil savings by 2025, where plausible deployment takes into account realistic stock turnover.*

We do not calculate Costs of Saved Energy (CSEs) directly for each military platform, but rather use the average CSE from the other sectors of *Winning the Oil Endgame* (commercial airplanes for military airplanes, commercial ships for navy ships, heavy and medium trucks for army ground vehicles). We calculated the average CSE for the military as the average of the fuel saved, weighted by the amount of fuel saved in each case. The CSE can be viewed in Table 13-1. Please refer to *Winning the Oil Endgame* page 41 for details on how CSEs are computed.

| Table 13-1: Summary of Cost of Saved Energy (by Fuel) | | |
|---|---|---|
| | *SOA* CSE | *CW* CSE |
| | $/bbl | $/bbl |
| Jet A - Aircraft | $24.81 | $15.95 |
| Resid - Navy Ships | -$1.19 | $0.64 |
| Distillate - Navy Ships | -$1.19 | $0.64 |
| Distillate - Ground Vehicles (heavy trucks) | $5.64 | $18.73 |
| Distillate - Ground Vehicles (medium trucks) | $44.18 | $27.94 |
| Total | $20.86 | $14.44 |

## 3. Conventions

We assume the same conventions as used in the *Winning the Oil Endgame*, which are described on page 39–42 of the report. Key conventions to note are our exclusive use of High Heating Value (HHV) for petroleum products as well as adopting the EIA's convention of expressing petroleum volume in Mbbl/d of oil equivalent (though we express here as Mbbl/y due to the comparatively small amount of fuel consumed by the military).

## 4. Efficiency savings in Air Force and Navy/Marine Aircraft platforms

The Air Force has a baseline use of 56.6 Mbbl/y and the 2025 projected forecast is 79.2 Mbbl/y. The baseline fuel use for Navy/Marine aircraft is 16.7 Mbbl/y and the 2025 projected use is 23.4 Mbbl/y. For all aircraft platforms, legacy and new, this analysis includes Integrated High Performance Turbine Engine Technology (IHPTET) advanced engine programs' engine improvements. IHPTET is projected to improve platform efficiency by 40 percent due to reduced fuel burn and higher thrust-to-weight in comparison to baseline engine technology[3]. The IHPTET improvement is reduced in some legacy platform cases due to recent or planned near-term engine upgrades.

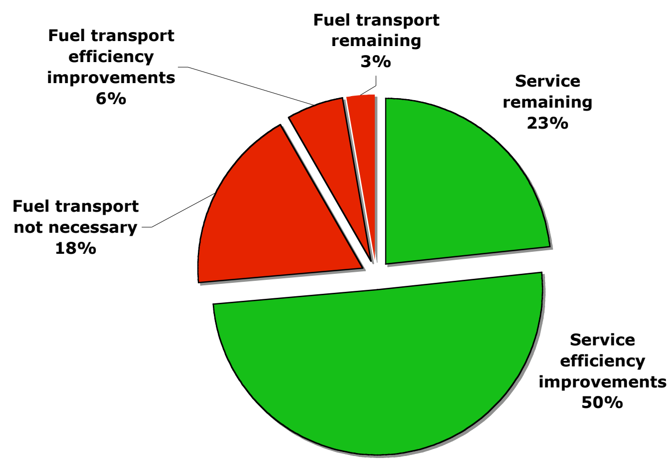


***Figure 13-2:*** *Air Force potential fuel reductions in 2025 (total 79.2 Mbbl/y)*

The overall demand for airborne refueling tankers is assumed to decline l airborne refueling capability. The model demand of all Air Force air refueled platforms and subtracts this reduction from the 2025 baseline demand for tankers.

[3] Presentation to DSB, 28 June 1999, *IHPTET Plan.ppt*, Paul Piscopo.

We assume maneuver demand for all transport aircraft to be reduced by improved cargo routing, flight planning, and air traffic technologies. These together are estimated to reduce the air miles traveled by cargo aircraft by approximately 13 percent[4]. In the model we apply this savings uniformly to all transport aircraft.

A number of the Air Force platforms deserve specific descriptions due to their disproportionate fuel use, unique replacement schedule, or unusual efficiency potentials. The KC-135 and KC-10 Stratotanker together consume more fuel than any other military platform, nearly three times the Navy's highest consuming ship platforms (Arliegh Burke and Spruance Class destroyers). Though first deployed in 1965, the life span of these airframes could theoretically extend to the 22nd century due to the low rate of flight hour accumulation of these aircraft. For the Plausible Deployment scenarios we assume that no replacement of the KC-135/KC-10 platforms occurs before 2025, despite recent attempts to fund a 767-based replacement for the oldest KC-135's.

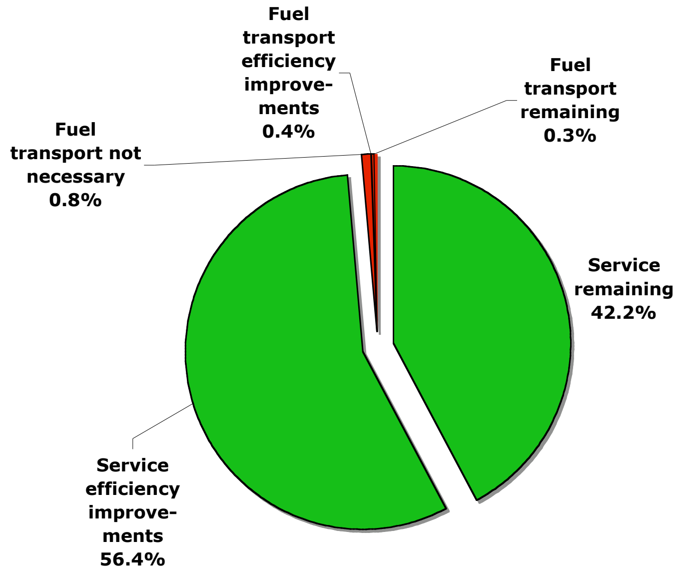


***Figure 13-3:*** *Navy/Marine aircraft potential fuel reductions in 2025 (total 23.4 Mbbl/y)*

The 1999 baseline data in this model includes about two-thirds of the KC-135 fleet upgraded from 1950's era TF33 turbojet engines to military versions of the 1990's vintage CFM56 turbofan engine. This upgrade alone results in up to a 27 percent increase in fuel efficiency for the platform. As the CFM56 engines are significantly more efficient than the baseline, the reduction in fuel burn due to future upgrades to IHPTET engines is assumed to be less than the 40 percent predicted for other platforms, estimated in this model at 20 percent. The KC-10 version is still deployed using its original 1970's era CF6 turbofan and should experience the 40 percent improvement projected from the IHPTET engine upgrade. New tanker platforms modeled in the Complete Deployment scenarios assume 787–like improvements to airframe and auxiliary systems for a *Conventional Wisdom* design[5] will lead to a 12 percent reduced annual fuel burn. The

[4] Defense Science Board Task Force on Improving Fuel Efficiency of Weapons Platforms, *More Capable Warfighting Through Reduced Fuel Burden,* Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, January 2001: pp. 28-30.

[5] From *Winning the Oil Endgame* Commercial aircraft appendix, *Technical Annex* Chapter 12.

Blended-Wing-Body (BWB) *State of the Art* design allows for a 27 percent reduction in fuel use[6].

The C-5 is the Air Force's largest transport aircraft. The C-5 entered service in 1970 and has been equally renowned for its ability to quickly move extraordinary quantities of outsized military equipment and also for chronic maintenance problems. Though the cost of maintenance makes the C-5 an attractive candidate for replacement, this is balanced by the fact that the fleet has about 80 percent of its structural life left and the demand to transport extremely heavy and outsized equipment is predicted to decrease over the next 20 years[7]. Demand for C-5 services in 2025 are estimated to be met 50 percent by existing C-5 platforms and 50 percent by a new design, for example the Air Force's concept for a Global Reach Transport[8].

The new C-5 designs assume 787–like improvements to airframe and auxiliary systems for a *Conventional Wisdom* design allows for a 12 percent reduced annual fuel burn.[9] BWB *State of the Art* design leads to a 32 percent reduced fuel burn.[10] The existing C-5 platforms are slated to undergo re-engining over the next decade[11] and we assume they will not undergo a second re-engining prior to 2025. The current re-engining program is conservatively assumed to improve platform fuel efficiency by 15 percent. All new designs are expected to benefit by a full 40 percent reduction in fuel burn due to IHPTET engine improvements relative to the baseline fuel consumption.

The Air Force's venerable fleet of C-141 Starlifters is currently undergoing decommissioning. The C-130 Hercules has been in production since the 1950's, the longest time period for any US military aircraft. This multipurpose platform is powered by four turbo-props and is designed for low speed tactical transport applications. A successor to the C-130 is not planned until 2020 timeframe[12].

For transport aircraft airframes *CW* assumes 787-like airframe improvement, 12 percent, and *SOA* assumes blended-wing-body (BWB). The Boeing engineers interviewed estimated BWB airframe applied in a cargo scenario (i.e. weight limited) would improve

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[6] BWB platform efficiency (including: MEA/systems lightweighting): 20-32 percent (Personal communication, 3 July 2004, Boeing BWB design engineering staff, range based upon size-bigger is better).

[7] Tirpak, John A., *Saving the Galaxy,* (January 2004). http://www.afa.org/magazine/Jan2004/0104galaxy.asp.

[8] Presentation to Defense Science Board, 28 June 1999, *Global Reach Transport.ppt*, Paul Piscopo.

[9] From *Winning the Oil Endgame* commercial aircraft appendix, *Technical Annex* Chapter 12, available at http://www.oilendgame.org/TechAnnex.html.

[10] Blended Wing Body (BWB) platform efficiency (including: MEA/systems lightweighting): 32 percent (Personal communication, 3 Jul 2004, Boeing BWB design engineering staff, range based upon size-bigger is better). The Boeing engineers cited a study result of 32 percent improvement for an equivalent BWB airframe versus an Airbus 380 in a cargo transport scenario. The cargo capacity of an A380 is assumed to be relatively similar to a C-5 for the purposes of this analysis.

[11] Tirpak, John A., *Saving the Galaxy,* (January 2004). http://www.afa.org/magazine/Jan2004/0104galaxy.asp.

[12] Presentation to DSB, 28 June 1999, *Future Systems.ppt*, Paul Piscopo.

efficiency over baseline "tube and wing" style designs by 20 percent to 32 percent, depending upon size, where larger efficiency improvements can be made on larger aircraft for BWB.

We assume reduced maneuver demand (i.e. vehicle miles traveled) for strike aircraft due to improved targeting, weather prediction, and air traffic control technologies.
New design *CW* and *SOA* fighter and strike aircraft are expected to benefit from integrated More Electric Aircraft (MEA) systems design that reduce weight and improve efficiency over current hydraulic and compressed air systems. (Note: the primary motivation for the military's pursuit of MEA is drastically improved reliability and reductions in support infrastructure). New design *SOA* fighter and strike aircraft are expected to also benefit from all advanced carbon-composite airframes, though we were unable to determine the impact of this improvement on fuel efficiency, we estimate it at 5 percent.

Due to their small contribution to overall fuel consumption, Air Force, Navy and Marine rotary-wing platforms were not included in the detailed analysis. The results of the fixed wing analysis are applied to rotary-wing platforms, which are not likely to be accurate, though this simplification will not affect the overall outcome of the analysis significantly.

Air Force cargo aircraft are used to transport Army equipment to theaters of war. An Army with significantly lighter vehicles, as is planned, could drastically reduce the Air Force transport fuel consumption in this role. At this time we have no data as to how often Air Force cargo aircraft transport heavy Army vehicles and can make no estimate of the additional benefit of lighter weight Army vehicles. It must be noted that current goals set for the Army of 2025 is to have much higher rate of transport both tactically and strategically, this indicates that lighter Army vehicles will also be matched with a much higher rate of air transport versus sealift, thus likely offsetting some of the efficiency gains with the inherently higher fuel consumption of aircraft transport.

The instantaneous potential for Air Force fuel savings from a *CW* technology portfolio is 63%. *SOA* technologies would yield a 68% improvement, as shown in Table 13-2.

| **Table 13-2: Air Force efficiency potential** | *CW* | *SOA* |
|---|---|---|
| Plausible Deployment | 57% | 60% |
| Complete Deployment | 63% | 68% |

The instantaneous potential for Navy/Marine aircraft fuel savings from a *CW* technology portfolio is 54%. *SOA* technologies would yield a 57% improvement, as shown in Table 13-3.

| **Table 13-3: Navy/Marine aircraft efficiency potential** | *CW* | *SOA* |
|---|---|---|
| Plausible Deployment | 51% | 53% |
| Complete Deployment | 54% | 57% |

## 5. Efficiency savings in Navy Ships

The baseline use for Navy ships is 16.9 Mbbl/y and the 2025 projected forecast is 23.7 Mbbl/y. A number of the ships currently in operation are scheduled to be replaced by nuclear powered aircraft carriers. The decommissioning of Navy fossil fueled aircraft carriers that were still operational in 1998 (Independence, Kitty Hawk, JFK, Constellation) alone eliminates 7.3 percent of Navy ship's fossil fuel consumption.

The Naval efficiency model considers energy use on a ship to be split between maneuver demand (moving and operating the ship) and hotel demand (energy used while the ship is stationary). These systems are often served by different powerplants on a ship and due to the upcoming transition to all-electric operation (using electricity to drive some operations formerly driven by waste heat). For this reason, the demand for hotel electricity is projected to increase significantly. Maneuver powerplants on legacy ships (gas turbines, boilers, diesels) are expected to experience marginal improvements due to retrofits and improved operations. Maneuver powerplants on new designs are assumed to be all gas turbines including the Navy's ICR advanced powerplant design and a portion of the IHPTET gas turbine improvements, estimated to reduce fuel consumption 50 percent.

Hotel electricity demand on warships (Destroyers, Frigates and Cruisers) is expected to increase 23.5 percent between baseline and 2025. This increase is due largely to the conversion of the water production from waste-heat-driven distillation and heating to all electric reverse osmosis and heating. Hotel efficiency improvements for both end-use and generators for all legacy platforms and new designs are based upon RMI's study of CG53 Ticonderoga-class cruiser. The split between platform fuel demand for maneuver and hotel is determined from given data for each platform's fuel consumption while underway versus while stationary. The demand for Navy underway replenishment oilers is assumed to decrease in direct proportion with fuel demand of the fossil fueled warships.

The Navy's Fast Sealift Ships (FSS) are designated primarily to transport Army equipment to theaters of war. During discussions with Fulcrum Corporation's consultant military marine architect it was identified that these ships are most often space limited due to the nature of logistics loading. Therefore, lighter weight, but similar sized Army equipment would most likely affect only the hydrodynamic efficiency of the transport ships not the total number of trips, i.e. miles traveled. The marine architect was unwilling to estimate the efficiency improvement due to this weight reduction, especially given the operating parameters of these ships, i.e. go as fast as you can all the time. Since these ships accounted for only ~2.3 percent of the Navy's ship fuel consumption in 1998 and the likely small percentage reduction in fuel consumption due to even a significantly lighter Army it is unlikely that the omission of this additional benefit will have a significant effect on the overall analysis.

*SOA* Navy ships are likely to take advantage of emerging lightweight composite hull technology. Though this might effectively improve efficiency of ships employing this technology it was indicated in the literature that the lighter hull would be used to add more weapons or fuel capacity and thus be unlikely to significantly improve ship maneuver efficiency.

The instantaneous potential for air platform fuel savings from a *CW* technology portfolio is 61%. *SOA* technologies would yield a 64% improvement, as shown in Table 13-4.

| **Table 13-4: Navy Ships efficiency potential** | | |
|---|---|---|
| | *CW* | *SOA* |
| Plausible Deployment | 28% | 30% |
| Complete Deployment | 61% | 64% |

**6. Efficiency savings in the Army**

Army ground vehicles have a baseline use of 7.1 Mbbl/y and a 2025 projected forecast of 9.9 Mbbl/y. The Army analysis has been hampered by the lack of platform specific consumption data. The data available relates to groups of platforms: combat vehicles, tracked support, aviation and trucks. The fuel consumption data is for a "battlefield day" modeled on a middle-east conflict scenario. Thus, we have extrapolated this data to the entire Army fuel consumption, including peacetime activities. The efficiency improvements for these platforms are presented in complete form, i.e., not broken down by propulsion, lightweighting, etc.[13]

Due to the variety of trucks used we did not apply our *SOA* Class-8 truck analysis directly to the truck fuel consumption. The Army has published estimates of 30–40 percent improvement in many truck platforms due to hybrid-engine technology alone. Thus we used an assumed 35 percent improvement for all new truck designs as an average that would include all applicable *SOA* Class-8 truck efficiency measures.

The instantaneous potential for air platform fuel savings from a *CW* technology portfolio is 75%. *SOA* technologies would yield a 78% improvement, as shown in Table 13-5.

| **Table 13-5: Army efficiency potential** | | |
|---|---|---|
| | *CW* | *SOA* |
| Plausible Deployment | 69% | 71% |
| Complete Deployment | 75% | 78% |

[13] LTC Sayler's presentation to the Defense Science Board in 1999.

| *Table 13-6 Conventional Wisdom* **Efficiency Concepts** | |
|---|---|
| **Efficiency concepts** | **Platform Groups** |
| New airframe (i.e. 7E7) replaces older platforms<br>Advanced turbines (IHPTET, commercial)<br>Improved air transport logistics routing<br>Reduced logistics load due to improved delivery reliability | New Air Force transport aircraft, commercial variants (7E7) |
| Improved air transport logistics routing<br>Re-engining of low-bypass turbo jets<br>Reduced logistics load due to improved delivery reliability<br>Lower weight Army equipment (e.g., IBCT) | Air Force transport aircraft, commercial variants (C-135, C-12, C-32, C-40) |
| Improved air transport logistics routing<br>Re-engining low-bypass turbo jets<br>Reduced logistics load due to improved delivery reliability<br>Lower weight Army equipment (e.g., AAN) | Air Force Transport Aircraft (C-5, C 141, C-17, C-130) |
| Re-engining low bypass turbo jets | B-52H, E-3, E-8 |
| Reduced airborne refueling demand | KC-10/135 |
| Advanced turbines (IHPTET, commercial)<br>Improved avionics (lighter weight, power draw) | New fixed wing intercept, CAP aircraft (F-22) |
| Reduced fleet due to replacement<br>Improved avionics (lighter weight, power draw) | All fixed wing intercept, CAP aircraft (F-15, F-14) |
| Improved tactical routing<br>Improved target recognition and intelligence<br>Improved weapons accuracy and lethality<br>Advanced turbines (IHPTET, commercial) | New fixed wing attack and close air support aircraft (JSF, etc?) |
| Reduced fleet due to replacement<br>Improved tactical routing<br>Improved target recognition and intelligence<br>Improved weapons accuracy and lethality | All fixed wing attack and close air support aircraft (F-16, F-18, F-15E, A-10, F-117, F-14B) |
| Advanced turbines (IHPTET, commercial)<br>Reduced hotel loads (optimum, CW)<br>Stern flap<br>Microturbine array APU | New Naval warships (oil fueled) |
| Reduced fleet due to replacement<br>Reduced hotels loads (retrofit)<br>Stern flap retrofit<br>Retrofit GTG with microturbine array | Naval warships (oil fueled), Cruisers, Frigates, Destroyers |
| APU or improved low-load turbine<br>Lighter armor (active?)<br>Lighter chassis | New tank platform |
| Reduced fleet due to replacement<br>Replacement with lighter armor brigades (IBCT)<br>APU retrofit | M1A2 Abrams tank, Bradley |
| Reduced armor fuel demand | Army battlefield fuel transport helicopters, CH-47 (line haul trucks below) |
| Reduced theater fuel demand<br>Stern flap retrofit | Navy tanker vessels (DESC?) |
| Reduced ship fuel demand<br>Stern flap retrofit | Navy oilers |
| Stern flap retrofit | All other navy ships (fossil fueled) |
| Tractor-trailer truck efficiency<br>- Aerodynamics<br>- Advanced diesel engines<br>- Low resistance tires<br>- Rankine bottoming cycle APU | Line haul trucks |
| Tractor-trailer truck efficiency<br>- Advanced diesel engines | Off-road misc. trucks |
| Commercial light duty vehicles<br>- hybrid-electric<br>- AFV procurement | All DoD light duty vehicles |

| *Table 13-7 State of the Art Efficiency Concepts* | |
|---|---|
| **Efficiency concepts** | **Platform Groups** |
| Hypertransport -<br>All composite airframe<br>Blended-wing-body/Adv. aero<br>Advanced turbines (IHPTET)<br>Improved air transport logistics routing<br>Re-engining low-bypass turbo jets<br>Reduced logistics load due to improved delivery reliability<br>Lower weight Army equipment (Army after Next) | New Air Force Transport Aircraft |
| Reduced fleet due to replacement<br>Improved air transport logistics routing<br>Re-engining low-bypass turbo jets<br>Reduced logistics load due to improved delivery reliability<br>Lower weight Army equipment (IBCT) | Current Air Force Transport Aircraft (C-5, C-141, C-135, C-130, C-17, C-12, C-32, C-40) |
| Hyperfighter (interceptor, CAP) -<br>All composite airframe<br>Advanced turbines (IHPTET) | New fixed wing intercept, CAP aircraft |
| Reduced fleet due to replacement | All fixed wing intercept, CAP aircraft (F-15, F-14) |
| Hyperfighter (attack) -<br>All composite airframe<br>Advanced turbines (IHPTET)<br>Improved tactical routing<br>Improved target recognition and intelligence<br>Improved weapons accuracy and lethality | New fixed wing attack and close air support aircraft |
| Reduced fleet due to replacement<br>Improved tactical routing<br>Improved target recognition and intelligence<br>Improved weapons accuracy and lethality | Current fixed wing attack and close air support aircraft (F-16, F-18, F-15E, A-10, F-117, F-14B) |
| Hyperwarship -<br>All composite hull<br>Advanced powerplant design for optimum efficiency at all loads<br>Lightweight/low power equipment/weapons systems<br>Advanced turbines (IHPTET)<br>Advanced hull design for hydrodynamic efficiency<br>Reduced hotel loads (optimum) | New Naval warships (fossil fueled) |
| APU retrofit/part-load turbine operation<br>Reduced hotel loads (retrofit)<br>Stern flap retrofit | All current navy warships (fossil fueled), Cruisers, Frigates, Destroyers |
| Hyperarmor -<br>Active armor<br>Composite chassis<br>Electric drive<br>Advanced powerplant design<br>Advanced turbines (IHPTET) | Army After Next, heavy armour |
| Reduced armor fuel demand | Army battlefield fuel transport helicopters, CH-47 (line haul trucks below) |
| Reduced warship fuel demand<br>Stern flap retrofit | Navy oilers |
| Reduced theater fuel demand<br>Stern flap retrofit | Navy tanker vessels (DESC?) |
| Stern flap retrofit | All other navy ships (fossil fueled) |
| Hypersemi -<br>Reduced armor fuel demand<br>Tractor-trailer truck efficiency<br>- Aerodynamics<br>- Composite strucure<br>- Hybrid drivetrain<br>- Advanced diesel engines<br>- Low resistance tires | Line haul trucks |
| Hypercar/truck -<br>Commercial light duty vehicles<br>- Hypercar, Hypertruck<br>- AFV procurement | All DoD light duty vehicles |