SYSTEMS STUDY OF GLOBAL RANGE AIRPOWER

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MIT 16.886

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OUTLINE

- Overview of Study
- Modeling Cost Structure
- Next Steps
- Questions Regarding Basing Costs

OVERVIEW OF STUDY

OBJECTIVES

The objectives of this study are (1) to examine the military value of domestically based aircraft with global un-refueled range and (2) to identify the enabling technologies needed to make such aircraft a viable alternative to current, shorter-range aircraft.

- **Examine the military value of global range platforms**
  - Understand ‘fully loaded’ costs of current aircraft and ballistic missiles
  - Identify impact of range and speed on campaign cost
- **Identify enabling technologies**
  - Survey prospective advanced technologies (airframe and propulsion)
  - Use physical models to predict potential performance improvements.
  - Propose preliminary vehicle designs
  - Integrate into cost model to predict cost benefit of new technologies

APPROACH - OVERVIEW

This global range aircraft systems study involves three stages:

- **Understand the existing cost structure**
  - Fixed and variable operating costs
  - Tanker logistics costs
  - Deployment and basing costs
  - Impact of aircraft performance parameters
- **Evaluate costs and benefits of different "global range" platforms**
  - Survey technologies, understand potential performance improvements
  - Use cost model to predict cost benefit of new technologies
- **Identify savings that can enable purchase of a "global range" platform**
  - Displacement of current platforms by global range platforms
  - Cost savings from performance improvements on existing platforms

DEFINING GLOBAL RANGE

Most regions of military interest to the US are within 6500 miles of CONUS

Location	Position		Distance from US Bases			
	Lat	Long	CONUS	w/ HI, AK	w/ Territories	w/ Diego Garcia
Belgrade	45.0	21.0	4581	4581	4581	4581
Kabul, Afghanistan	34.5	69.2	6680	5142	4888	2899
Baghdad, Iraq	33.3	44.4	6048	5563	5563	3359
Mosul, Iraq	36.3	43.2	5848	5370	5370	3564
Beijing, China	39.8	116.5	5417	3678	2501	2501
Shanghai, China	32.1	118.8	5769	4070	2088	2088
Taipei, Taiwan	25.1	121.5	6053	4414	1716	1716
Pyongyang, N. Korea	39.0	125.7	5152	3459	2114	2114
Monrovia, Liberia	6.3	(10.8)	4561	4561	3750	3750
Dili, East Timor	(8.6)	125.6	7679	5150	2027	2027
Ulaanbaatar, Mongolia	47.9	106.8	5226	3468	3221	3221
Cape Town, S. Africa	(34.0)	18.6	7791	7791	6582	3881
Tierra del Fuego, Chile	(54.8)	(70.2)	5734	4916	4916	4916

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FIGURES OF MERIT

Current results focus on cost [dollars] per strike, airlift, or refueling payload in [tons]

Mission	**Figure of Merit**	
	$/Ton	$/Ton-Hours
Nuclear Strike	X	
Conventional Strike	X	
Close Air Support		X
Combat Air Patrol		X
Airlift	X	
Refueling	X	
Reconnaissance		X
Electronic Surveillance		X

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PLATFORMS STUDIED

The study considers five major platform types and sixteen platforms

Platform Type	Platforms	Missions	Metric
Strike Aircraft	F-15E F-16C/D F-117A OA/A-10A	Strike Loiter	[$/ton] [$/ton-hour]
Long Range Bomber	B-1B B-52H B-2A	Strike Loiter	[$/ton] [$/ton-hour]
Airlift	C-5A/B C-17A C-130E/H C-141A/B/C	Airlift	[$/ton]
Aerial Refueling	KC-10A KC-135E/R	Refueling	[$/gallon]
Recon	U-2S RQ-4A	Loiter	[$/ton-hour]

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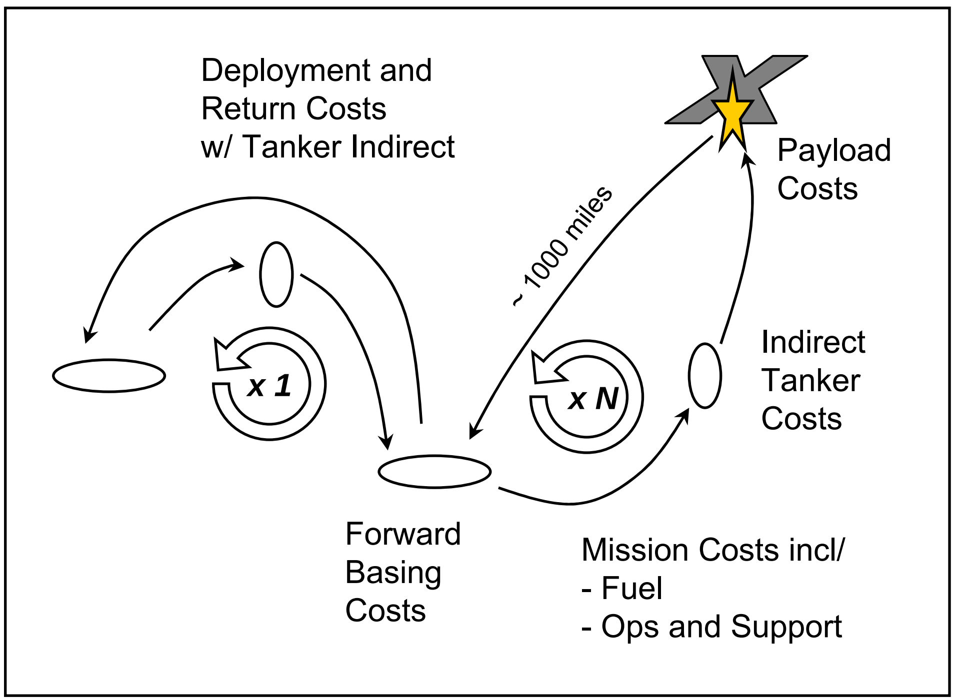
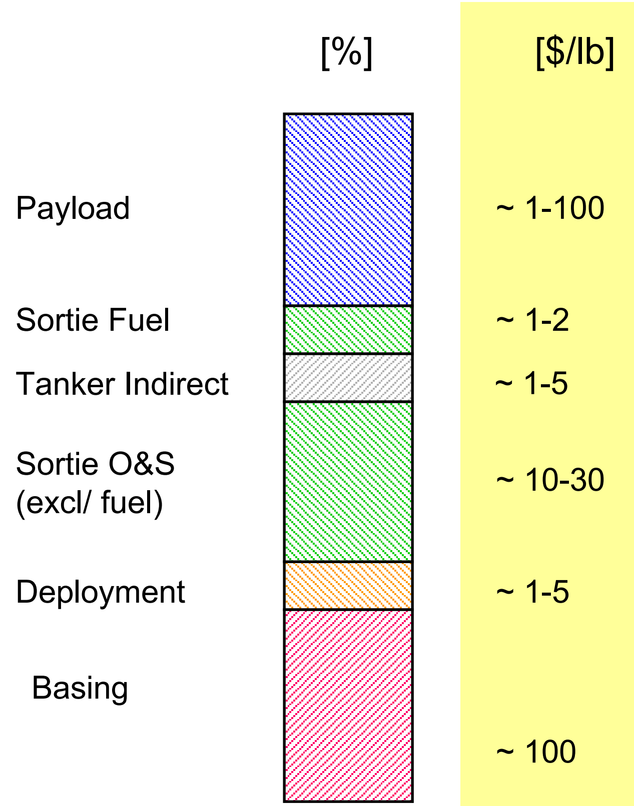
MODELING THE EXISTING COST STRUCTURE

COST OF AF INFRASTRUCTURE

The costs associated with the current USAF infrastructure were divided into six major categories….

Typical Strike Campaign Profile





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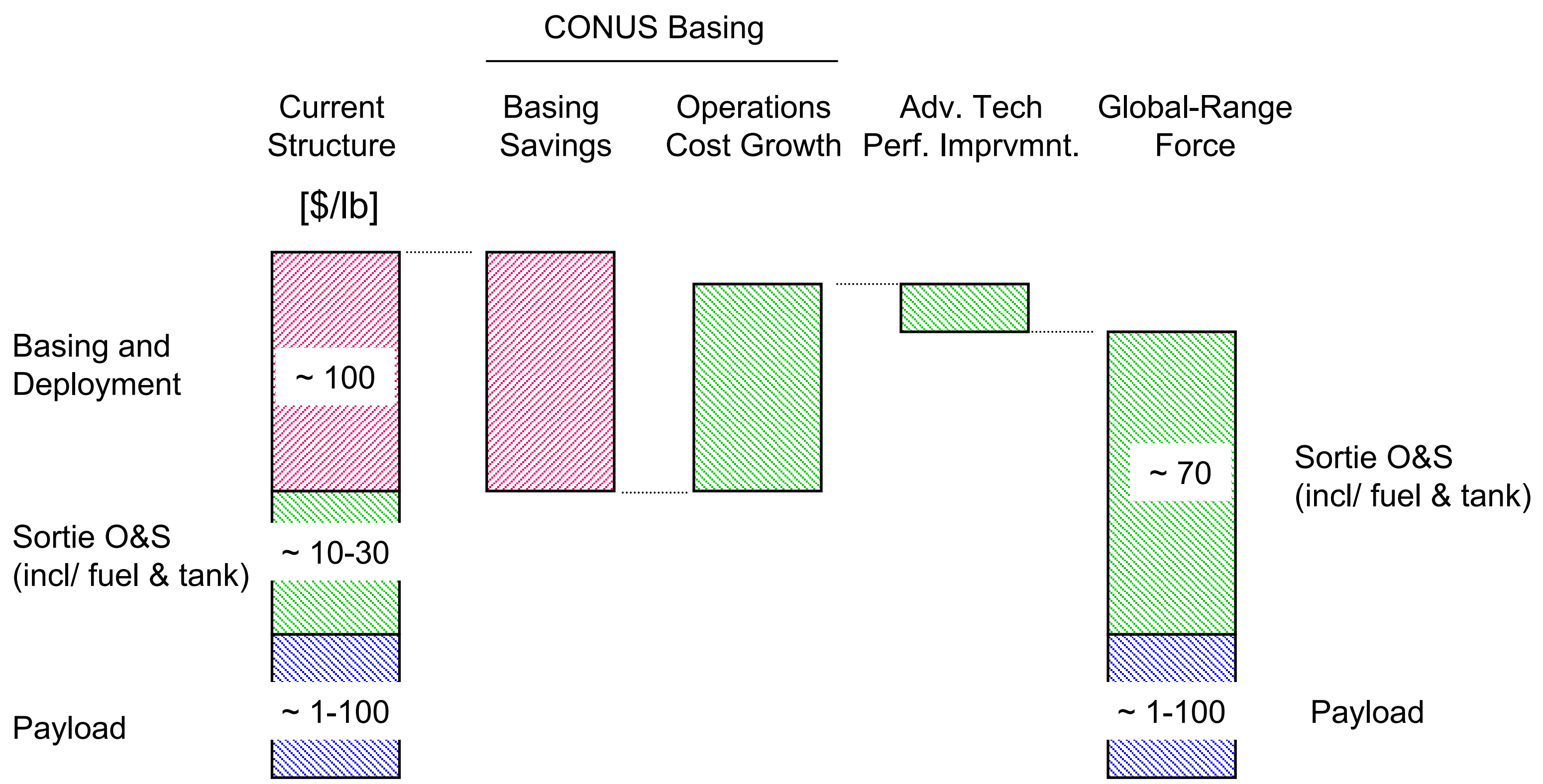
COST OF AF INFRASTRUCTURE

Global-range missions substitute operational costs for overseas-basing costs, potentially leading to an overall cost savings.



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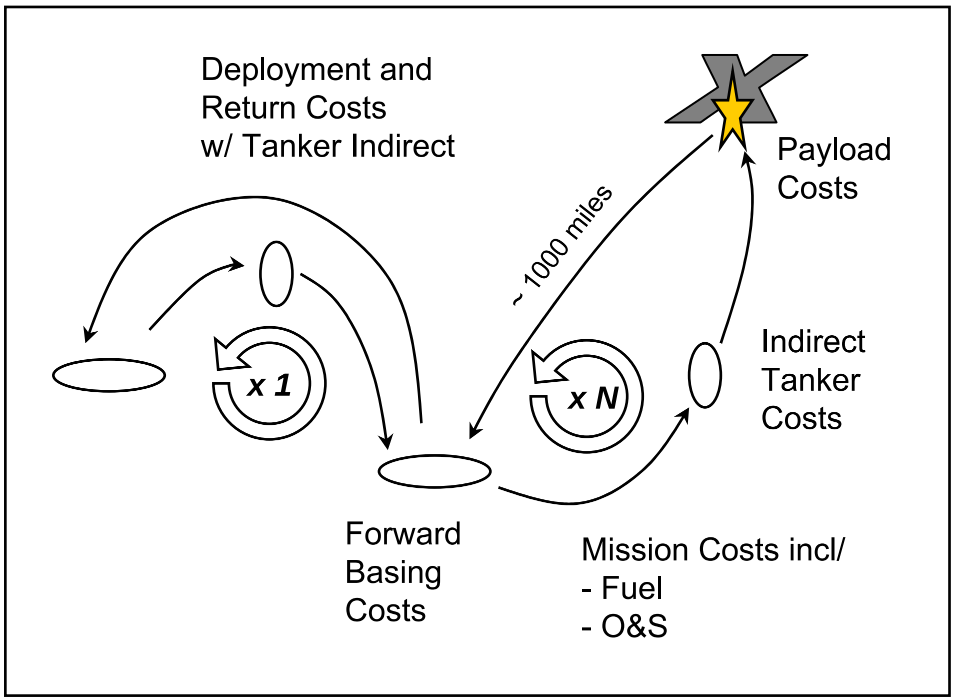
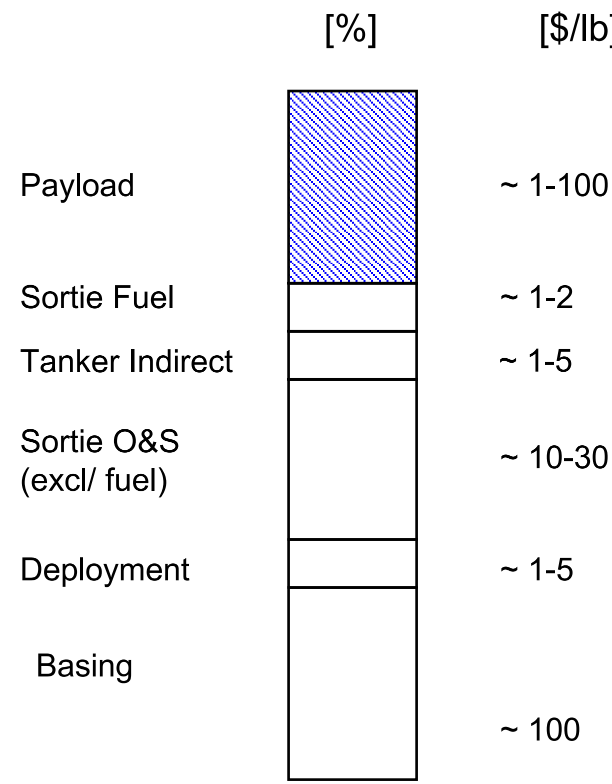
PAYLOAD COSTS

PAYLOAD COSTS

Depending on the sophistication of the payload, payload costs can be the smallest or largest cost category for a strike mission, with a cost range of 1-100 $/lb. Standard JDAM guided bombs cost approximately $10/lb.

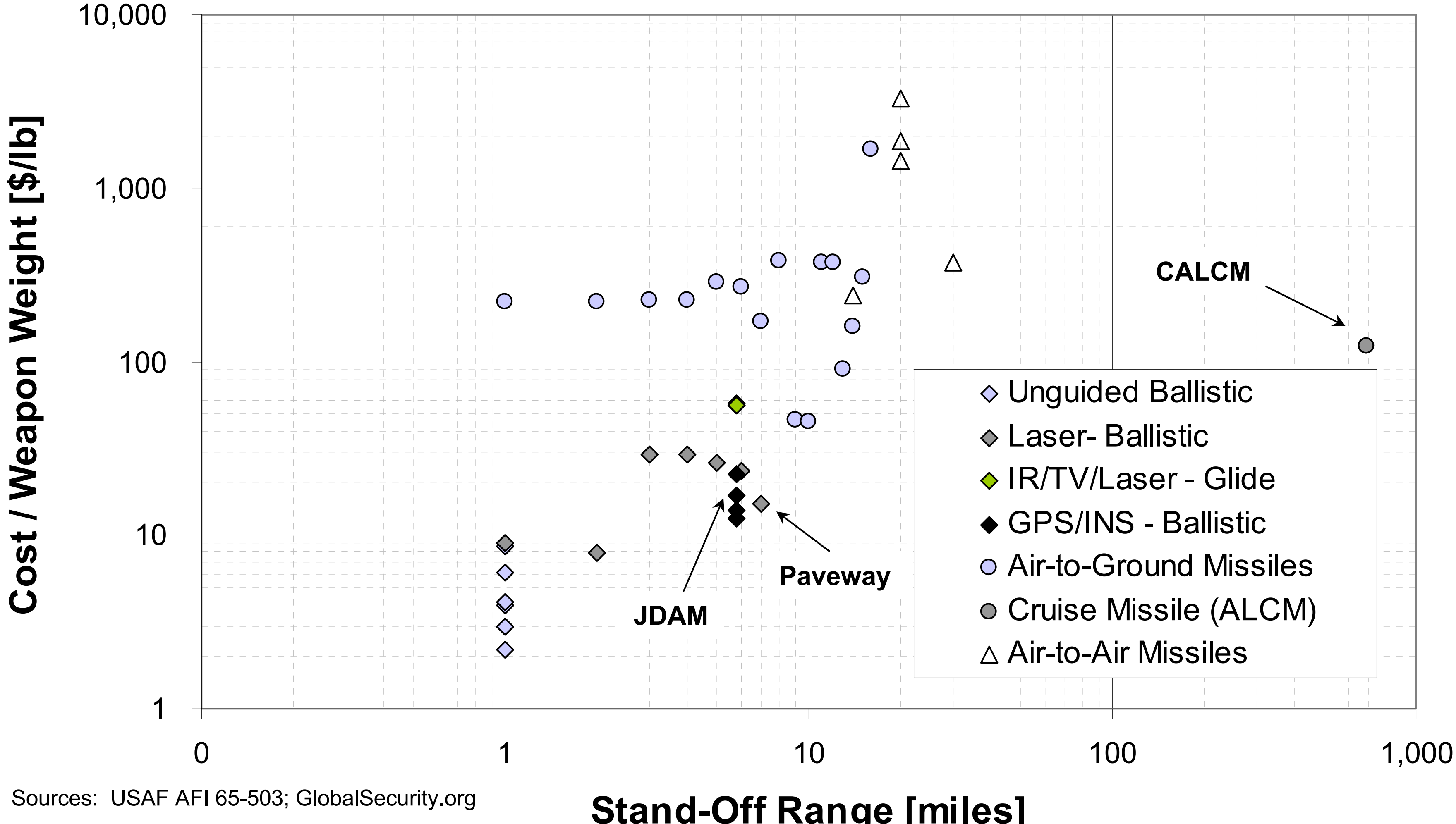
Typical Strike Campaign Profile





PAYLOAD COSTS vs. STAND-OFF RANGE

Air-to-ground payload cost ranges up to 300 $/lb, depending on stand-off range and munition type.



Sources: USAF AFI 65-503; GlobalSecurity.org

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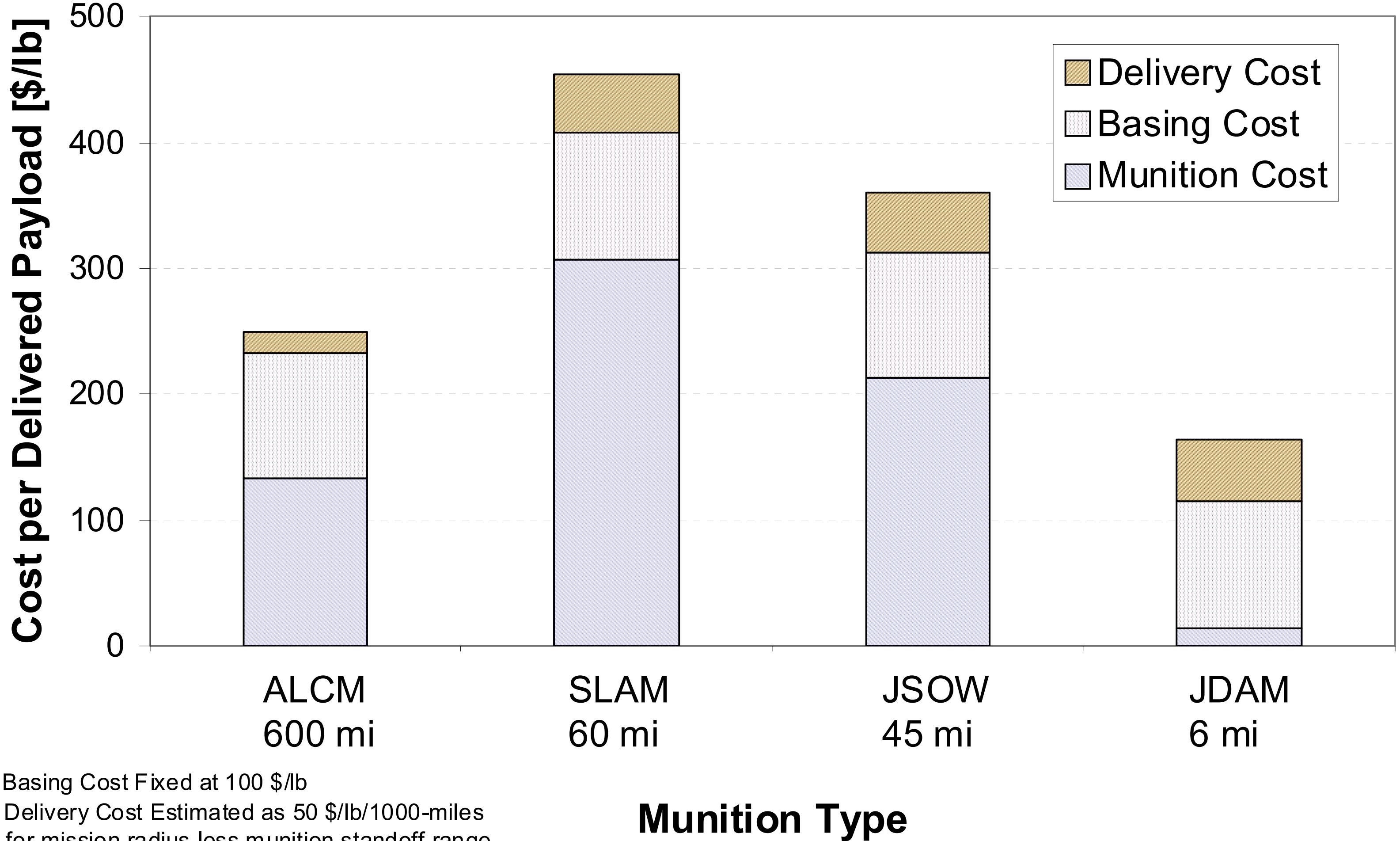
TOTAL STRIKE COST



* Basing Cost Fixed at 100 $/lb

** Delivery Cost Estimated as 50 $/lb/1000-miles for mission radius less munition standoff range.

*^ 1000-mile radius from forward base to target.

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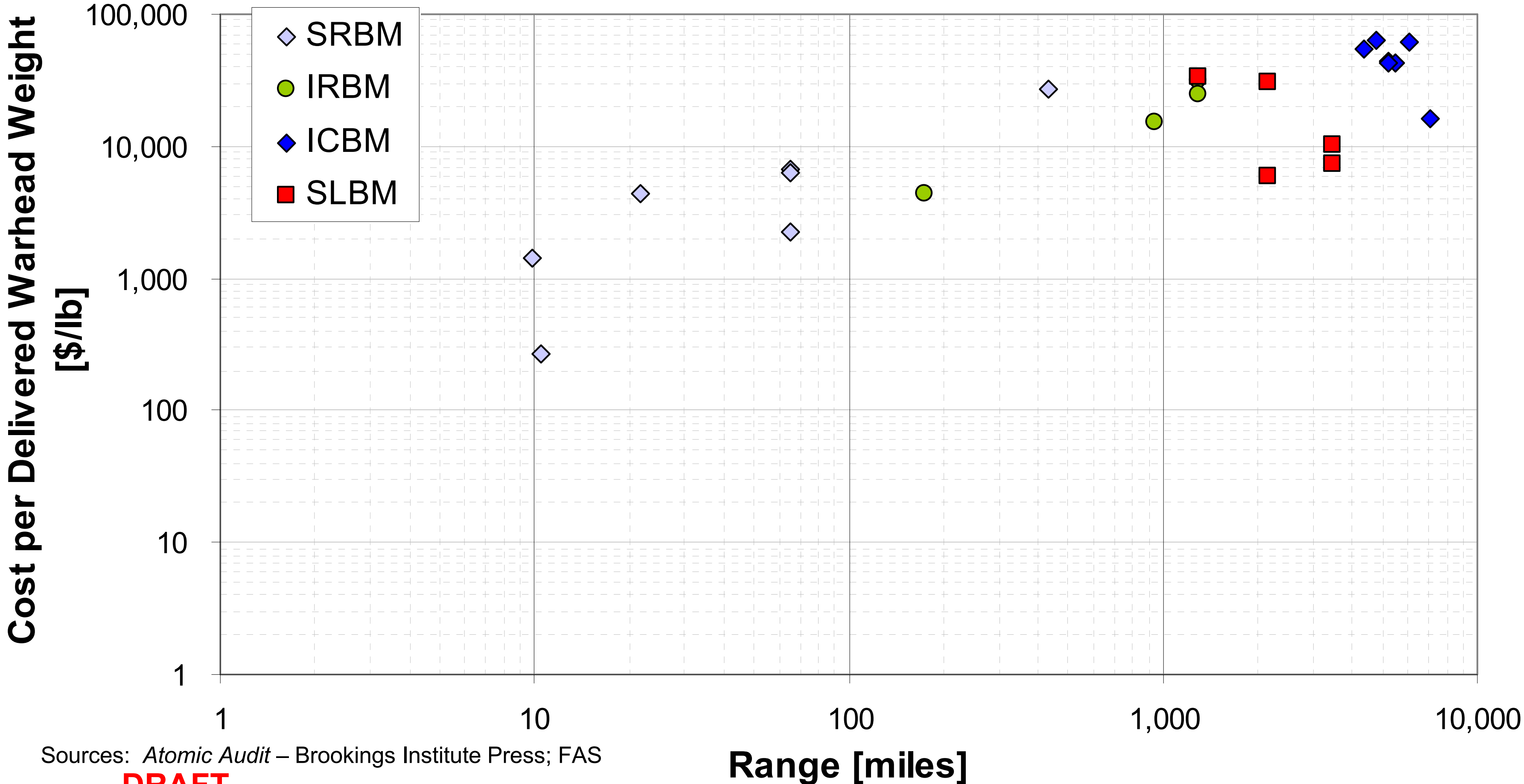
BALLISTIC MISSILE COST vs. RANGE

Delivery by existing ICBMs costs from $10,000/lb to $100,000/lb.



Sources: *Atomic Audit* – Brookings Institute Press; FAS

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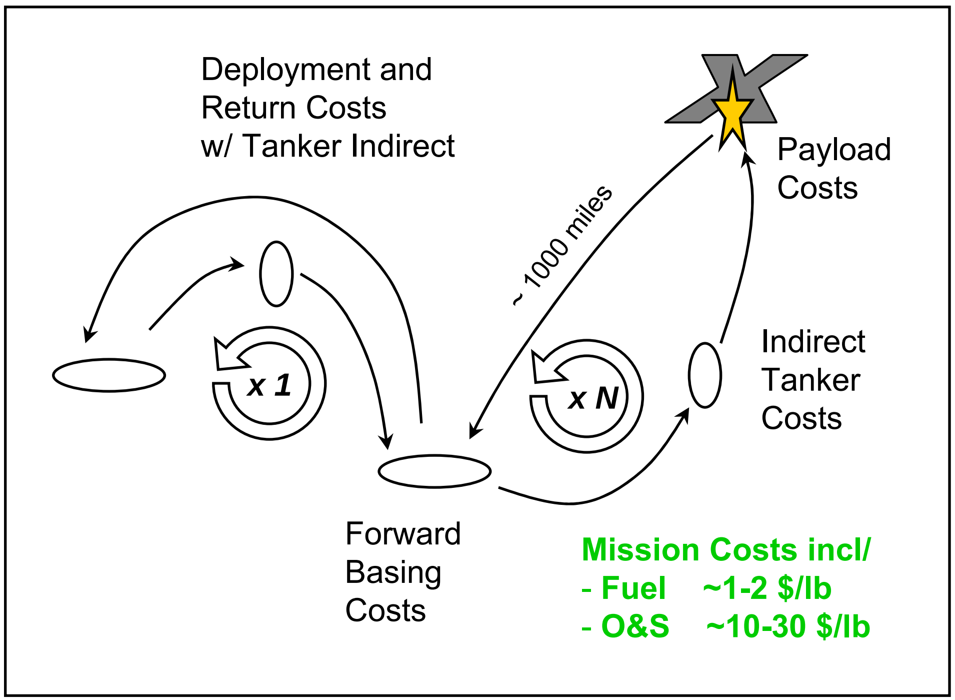
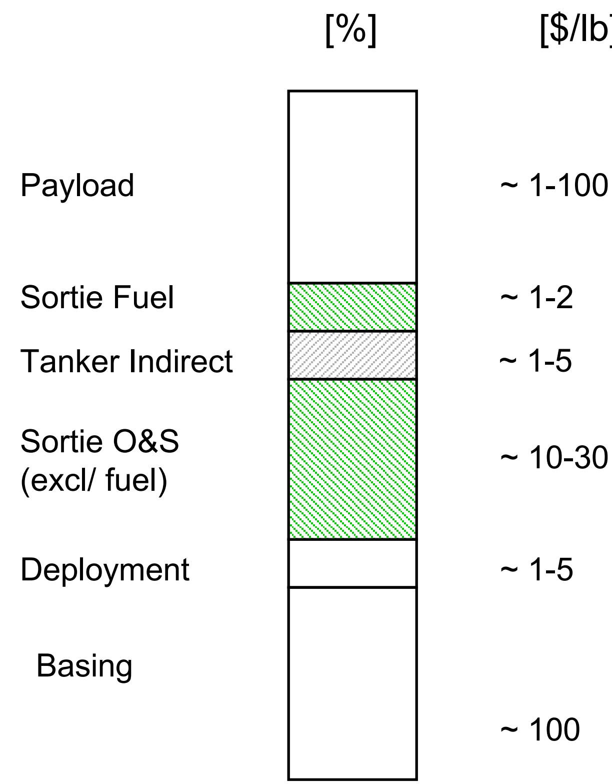
OPERATING AND SUPPORT COSTS

OPERATING AND SUPPORT COSTS

Operations and support costs account represent the second largest non-payload cost category, with a typical cost on the order of 10-30 $/lb for a 1000 mile mission.

Typical Strike Campaign Profile





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MODELING PLATFORM OPERATING COSTS

Operating costs for each platform are built up from publicly available USAF budget data and are allocated per aircraft or per flying hour.

Cost	Input Data	Allocation	Data Source*^
Crew/Ops	Crew Levels Other Ops Personnel Pay Rates	Aircraft	AFI 65-503
Fuel	Range Payload Fuel Spot Price	Flying Hour*	Performance. Model AFI 65-503
Maintenance	Maintenance Crew Levels Pay Rates	Aircraft	AFI 65-503
	Organic Maint by A/C Contract Maint by A/C	Aircraft	AFI 65-503
	Organic Maint by FH Contract Maint by FH	Flying Hour	AFI 65-503
Depreciation	Fly-Away Cost Service Life	Flying Hour	AFI 65-503 GlobalSecurity.Org
Attrition	Fly-Away Cost Attrition Rates	Flying Hour**	AFI 65-503

Notes:

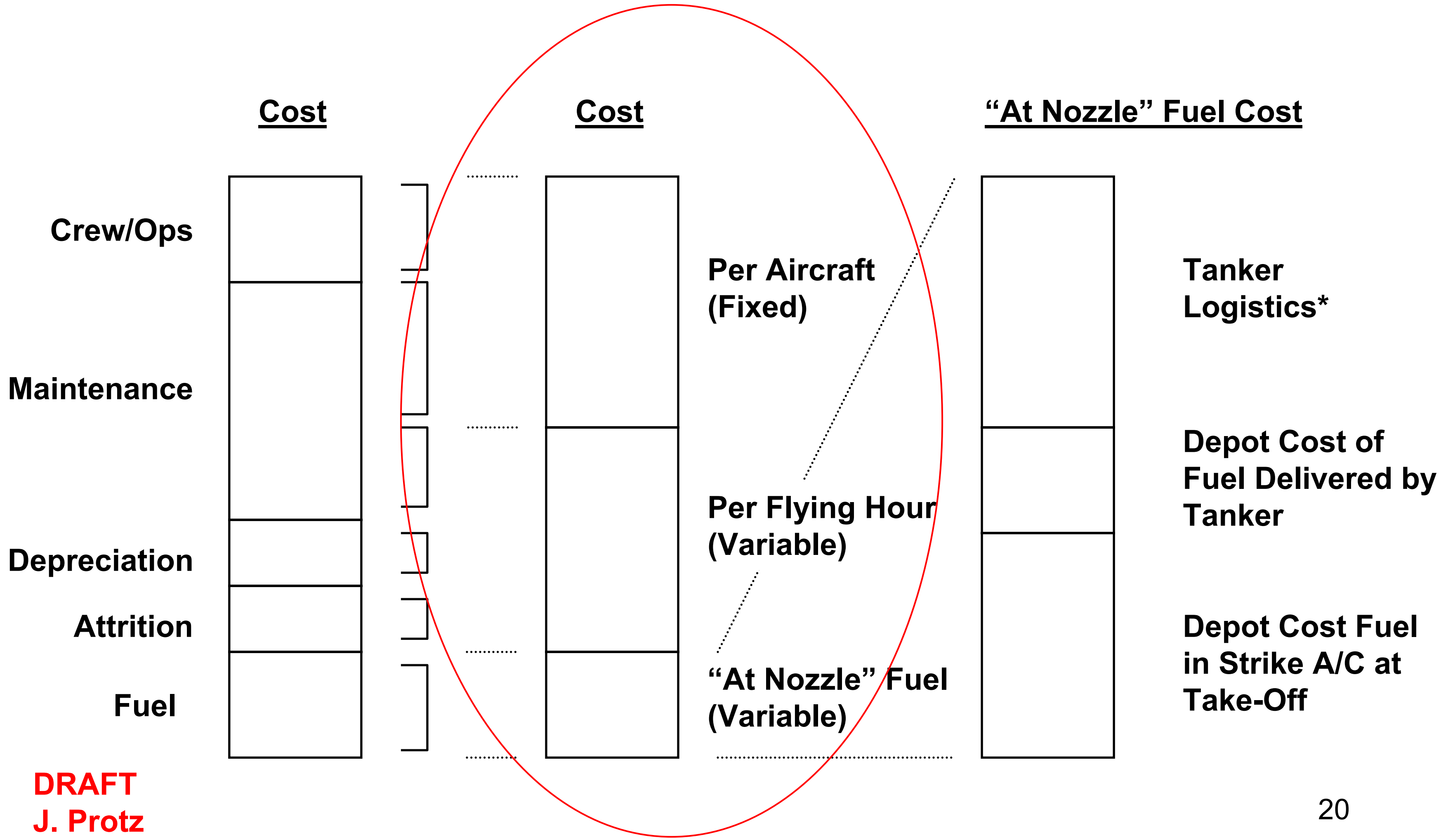
* Fuel Cost is allocated nonlinearly to flying hours as a function of range using the Performance Model.

** AFI 665-503 Attrition rate model is linearized around FY 03.

*^ AFI 65-503 data can be found at www.saffm.hq.af.mil GlobalSecurity.Org data can be found at www.globalsecurity.org

SIMPLIFYING OPERATING COSTS

Operating costs for each platform are reduced to three primary cost types: (1) Fuel (Variable), (2) Per-Flying Hour (Variable), (3) Per-Aircraft (Fixed)



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SHORT RANGE – O&S COSTS DOMINATE

For short-range missions, both O&S and fuel costs are proportional to mission radius.
O&S costs (fully loaded) are the dominant contributor for current platforms.

Short Range

$$\frac{R}{V} << \frac{L/D}{TSFC}$$

$$\frac{COST_{FUEL}}{PAY} \approx P_{FUEL}\cdot\left(1+\frac{EMPTY}{PAY_{MAX}}\right)\cdot\frac{TSFC}{L/D}\cdot\frac{R}{V}\cdot\left(1+\frac{FH_{PEACE}}{FH_{COMBAT}}\right)$$

$$\frac{COST_{O\&S}}{PAY} \approx \left[\frac{O\&S_{PAA}}{FH_{PAA}}+O\&S_{FH}\right]\cdot\frac{1}{PAY_{MAX}}\cdot\frac{R}{V}\cdot\left(1+\frac{FH_{PEACE}}{FH_{COMBAT}}\right)$$

Unrefueled w/
O&S costs assumed
by flight hour or yearly

$$\frac{COST}{PAY} \approx \underbrace{\frac{1/V}{PAY_{MAX}}\cdot\left[\frac{O\&S_{PAA}}{FH_{PAA}}+O\&S_{FH}\right]}_{\text{O\&S Costs}}\cdot R+\underbrace{P_{FUEL}\cdot\left[1+\frac{EMPTY}{PAY_{MAX}}\right]\cdot\frac{TSFC}{L/D}\cdot\frac{1}{V}}_{\text{Fuel Costs}}\cdot R \;\;\mathbf{x}\;\; \underbrace{\left(1+\frac{FH_{PEACE}}{FH_{COMBAT}}\right)}_{\text{Utilization Factor}}$$

Platforms	O&S Costs [$/lb/1000 miles]	Fuel Costs [$/lb/1000 miles]	x Utilization Factor
OA/A-10A	2.5	0.3	10
F-117A	-	-	-
F-15E	2.2	0.3	10
F-16C/D	3.3	0.2	10
B-1B	1.1	0.1	10
B-2A	-	-	-
B-52H	1.0	0.1	10
Hypothetical UCAV/URAV	1.1	0.05	1

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COST AND PLATFORM "PRODUCTIVITY"

The added O&S costs of long range missions capture the effect of lower platform productivity.

	Forward Basing	CONUS-Basing (Maintain Intensity)	CONUS-Basing (Maintain Asset Level)
Mission Radius	1000-mile mission radius	1000-mile mission radius	1000-mile mission radius
Objective	100 tons on target 1 day	100 tons on target 1 day	100 tons on target 10 days
Platform Specs ↓	10 tons/aircraft 500 mph cruise speed 20 flight-hrs/day/aircraft	10 tons/aircraft 500 mph cruise speed 20 flight-hrs/day/aircraft	10 tons/aircraft 500 mph cruise speed 20 flight-hrs/day/aircraft
Execution Plan ↓	10 tons/sortie 2 flight-hrs/sortie 10 sorties/day 10 total sorties	10 tons/sortie 2 flight-hrs/sortie 10 sorties/day 10 total sorties	10 tons/sortie 2 flight-hrs/sortie 1 sorties/day 10 total sorties
Assets Used	1 aircraft	10 aircraft	1 aircraft
Cost (Flight Hours)	20 total flight-hrs 20 flight-hrs/aircraft 0.2 flight-hrs/ton	200 total flight-hrs 20 flight-hrs/aircraft 2 flight-hrs/ton	200 total flight-hrs 200 flight-hrs/aircraft 2 flight-hrs/ton

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PLATFORM DEPRECIATION

The post-Cold War threat environment makes modern platforms stable, long-term assets rather than the "wasting" assets they were during the Cold War. As a result, depreciation has become a cost that is keyed to flight hours.

Year	US Fighter Introductions	Soviet Fighter Introductions
1945-1955	F80, F82, F84, F86, F89, F94, F100	MIG15, MIG17, MIG19
1956-1965	F101, F102, F104, F105, F106, F4, F5	MIG21, Su9, Su15
1966-1975	F111, F15	MIG23, MIG25, MIG27
1976-1985	F16, F117	Su 27, MIG 29, MIG 31
1986-1995	F15E	Su 30
1996-2003	F22	

Notes

Cold War (1945-1985)

US platforms faced rapidly-evolving, direct competition from adversaries.

Effectiveness of fielded platforms declined yearly due to adversary technology development and deployment.

Platforms were "wasting" assets.

Depreciation was a fixed annual cost.

Post-Cold War (1986-2003)

US platforms no longer face rapidly-evolving, direct competition.

They are now long-term assets.

Depreciation is now a variable cost.

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MODELING AERIAL REFUELING COSTS

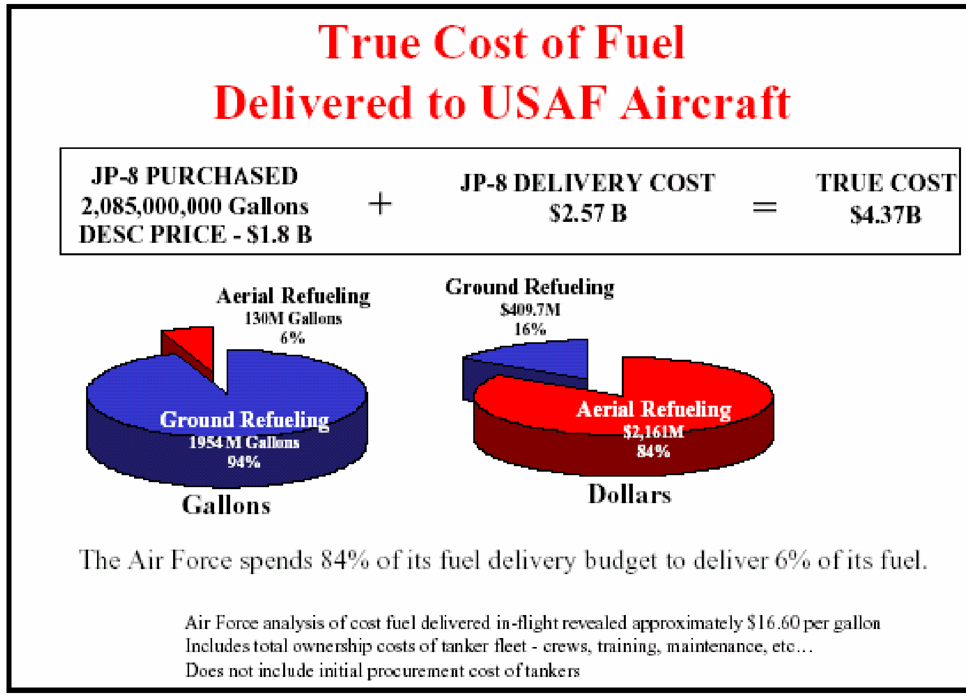
AERIAL REFUELING IS EXPENSIVE

Fuel delivered via aerial refueling is considerably more expensive than fuel carried at takeoff due to the underlying operations and support (O&S) of the tanker fleet.

Depot cost of USAF JP-8: $0.99 / gal

Average cost of USAF JP-8: $2.1 / gal

USAF/DSB estimated cost of tanker JP-8 at the nozzle: $16.60 / gal

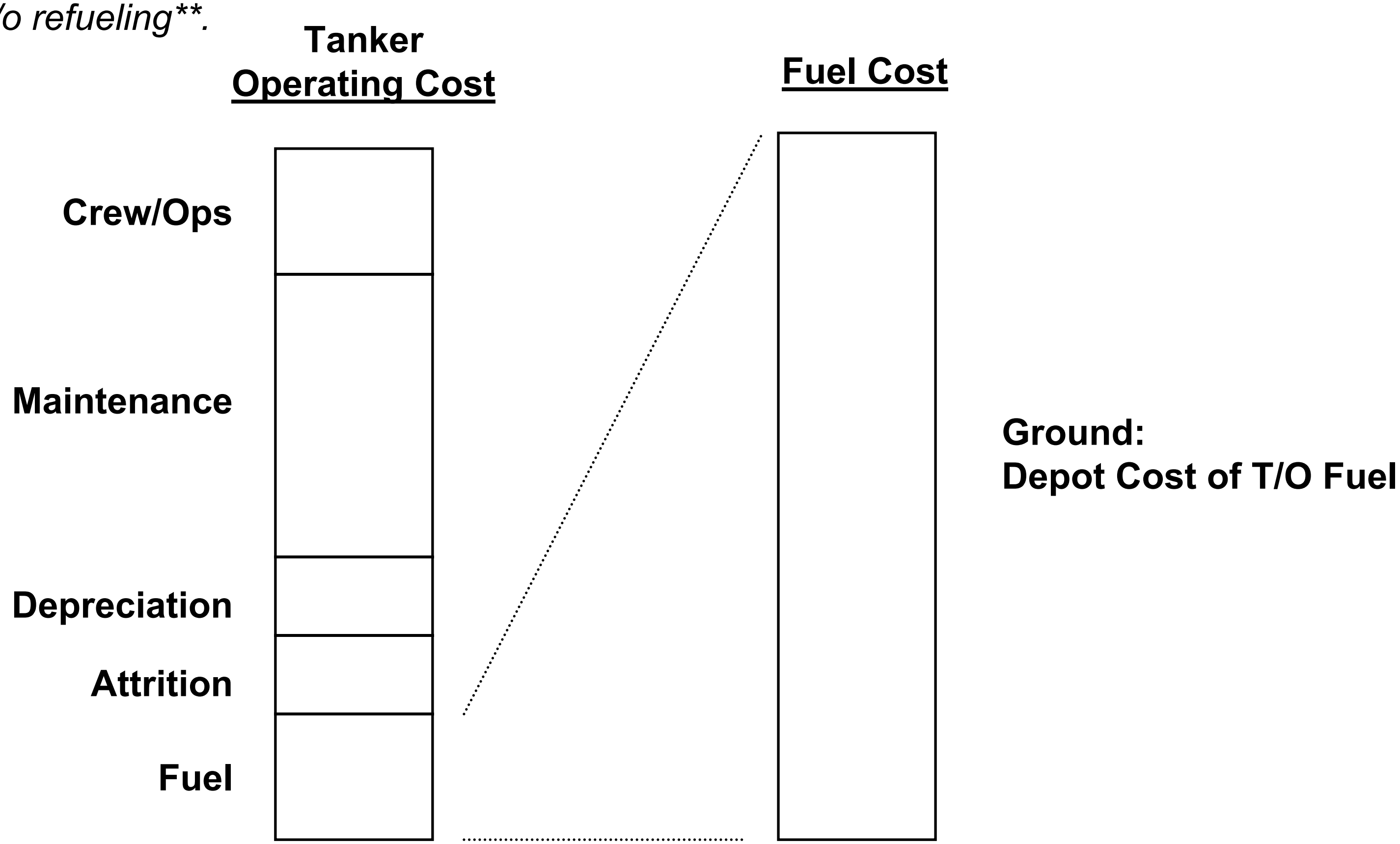


"The DoD currently prices fuel based on the wholesale refinery price and does not include the cost of delivery to its customers. This prevents an end-to-end view of fuel utilization in decision making, does not reflect the DoD's true fuel costs, masks energy efficiency benefits, and distorts platform design choices."

– Defense Science Board, January 2001

MODELING TANKER LOGISTICS COSTS

*Tanker logistics costs are modeled with the same approach used for strike aircraft. In the case of tankers, the "payload" is the transferred fuel. Tanker aircraft are modeled w/o refueling**.*



Notes:
- Tanker logistics includes cost of fuel burned by tanker, tanker variable operating costs, and tanker fixed costs allocated by flying hour.

** Except KC-10A which is modeled w/ KC-10A to KC-10A refueling for very long ranges.

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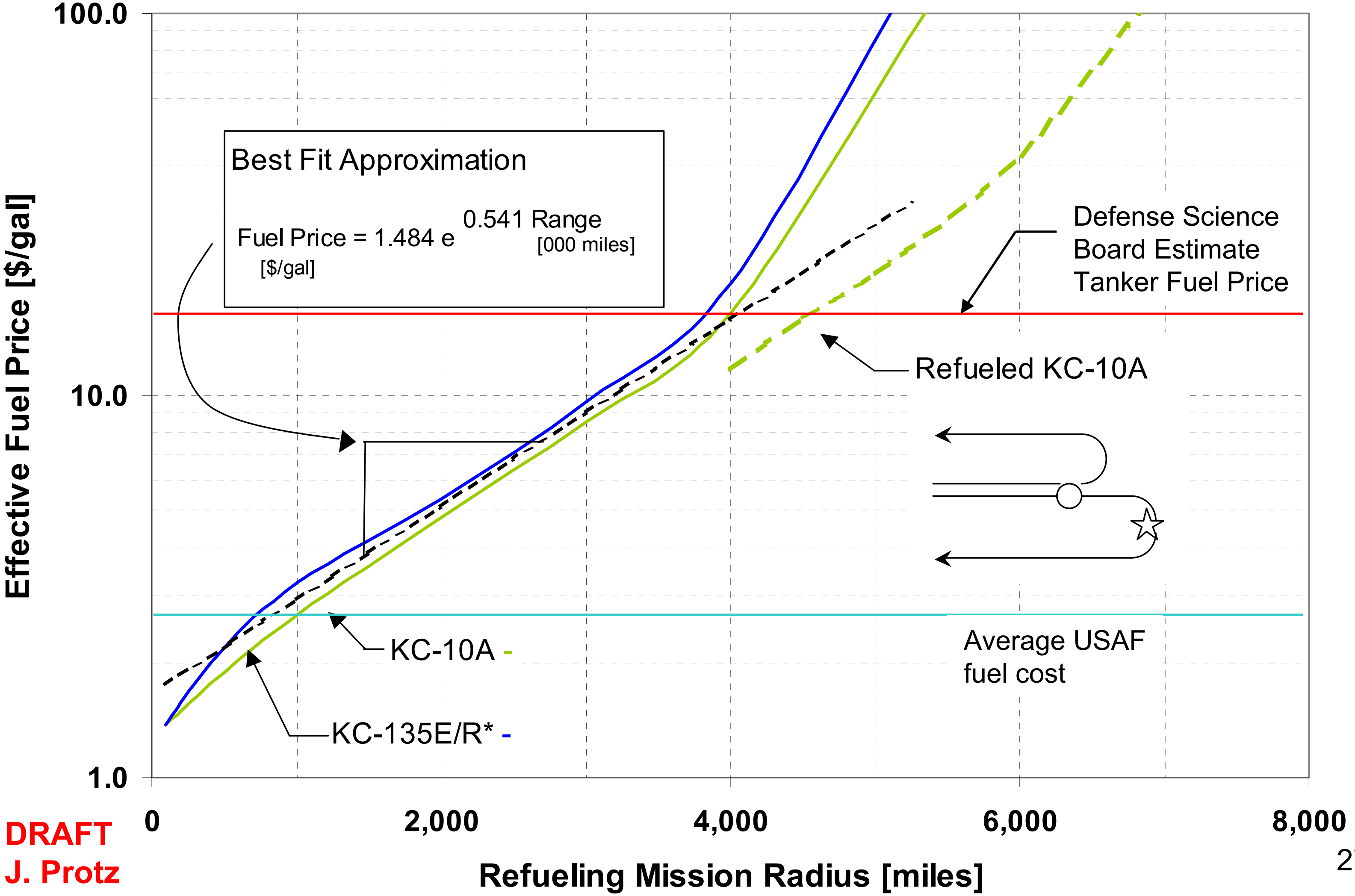
EXPONENTIAL COST OF REFUELING

The fully-loaded (w/ tanker O&S costs) effective cost of fuel from a tanker grows exponentially with the refueling mission radius.



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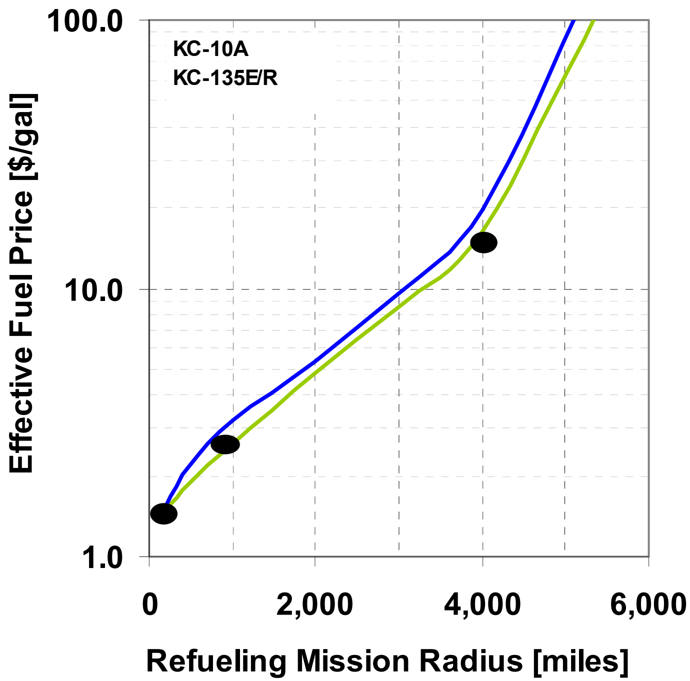
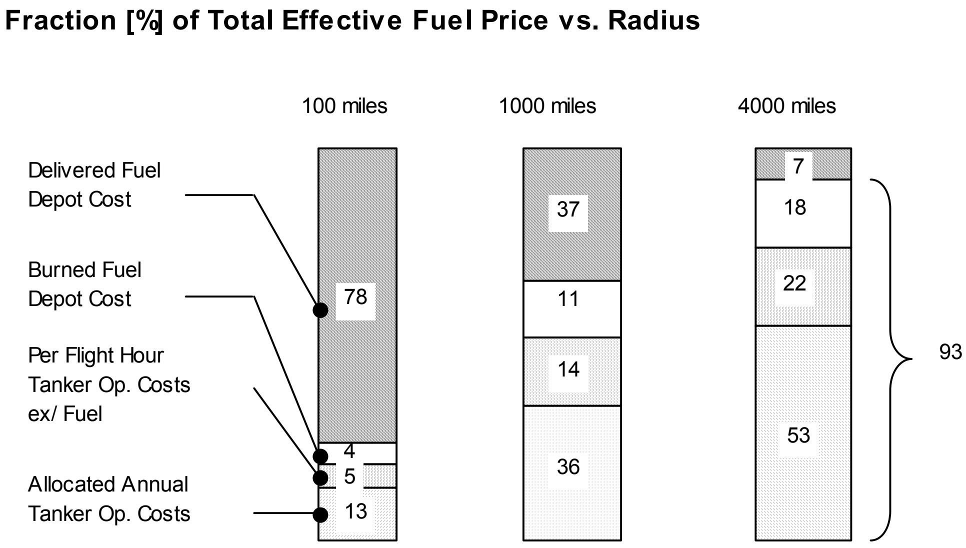
SOURCES OF REFUELING COSTS

Tanker operating and support costs represent the the bulk of the effective fuel cost for refueling missions beyond a 500 mile radius.





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REFUELING COST IMPLICATIONS

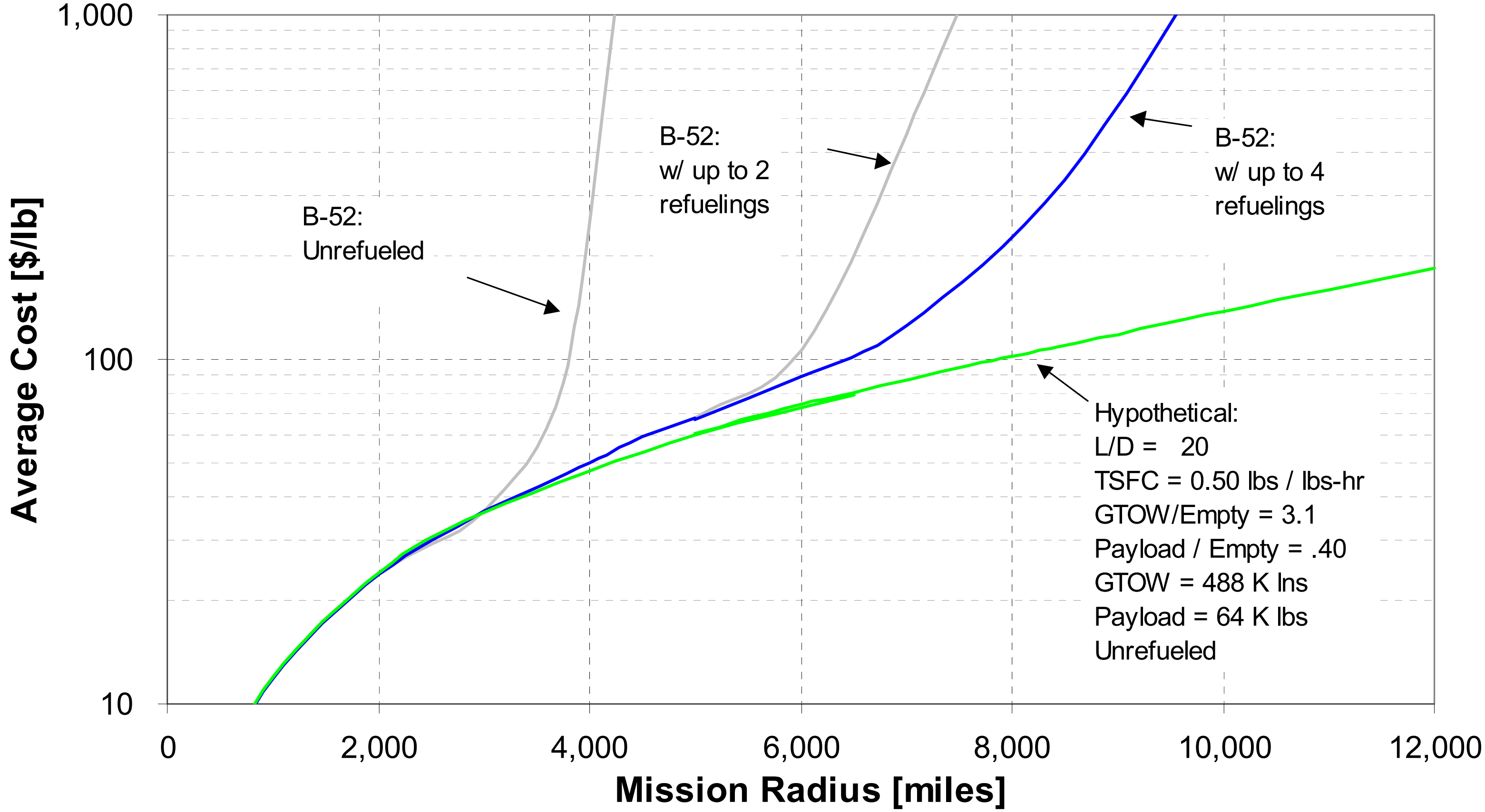
- **Short range refueling missions are comparatively inexpensive.**
  - "At the nozzle" fuel cost is only $1.50 (vs. $0.99 depot) at 100 miles.
  - Forward-based tankers can be an effective way to increase tempo.

- **Long-range missions that depend on aerial refueling are expensive.**
  - "At the nozzle" fuel cost is already $5 / gallon at 2000 miles.
  - "At the nozzle" cost grows exponentially with range

- **Implication**: Un-refueled long-range aircraft are likely to be no more expensive than tanker-supported aircraft operating from remote bases (e.g. Diego Garcia)

AVERAGE MISSION COST

The average mission costs (O&S plus tankers) range from $10/lb for a 1000-mile mission radius to $100/lb for a 6500-mile mission radius.



*** Includes tanker costs. Excludes payload, basing, and deployment.**

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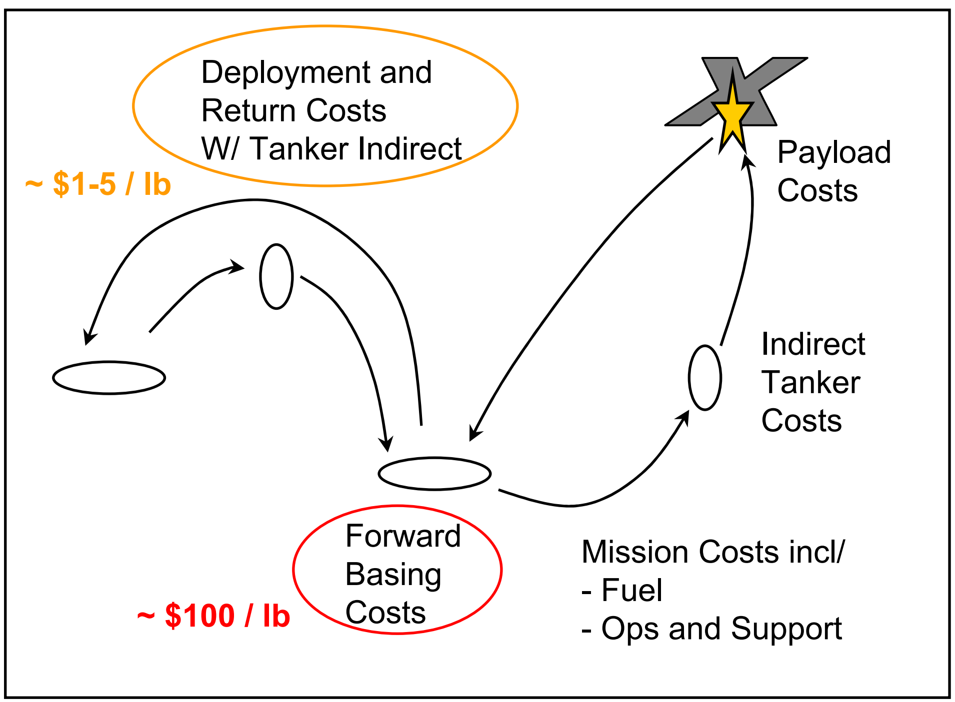
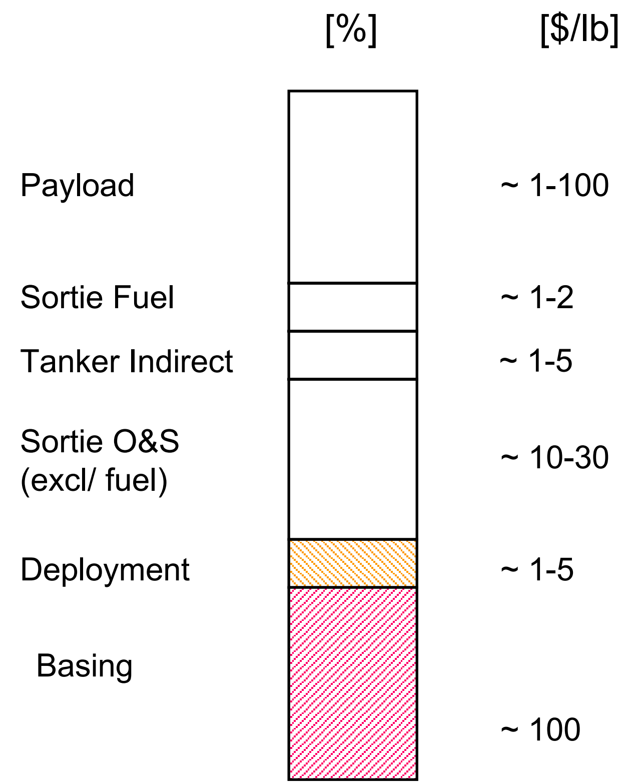
BASING AND DEPLOYMENT COSTS

THE COSTS OF FORWARD DEPLOYMENT

Deploying strike aircraft from their home bases to their forward bases during a campaign leads to substantial basing and deployment costs. These costs can represent a significant portion of total cost of a campaign.

Forward Deployed Mission





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MODELING OVERSEAS BASING COSTS

Basing costs were modeled using the following simple cost model:

Footprint

Annual Base Operating Costs — **Campaign Intensity** — **Campaign Frequency**

$$\frac{BASE\_COST}{PAYLOAD} \approx \underbrace{\left[\frac{COST/YEAR}{BASE}\right]}_{\text{Annual Base Operating Costs}} \cdot \underbrace{\left[BASES\right]}_{\text{Footprint}} \Big/ \underbrace{\left[\frac{PAYLOAD}{CAMPAIGN}\right]}_{\text{Campaign Intensity}} \cdot \underbrace{\left[\frac{CAMPAIGN}{YEAR}\right]}_{\text{Campaign Frequency}}$$

~ $100M / base (COST / YEAR per BASE)

~ 10-20 major bases (BASES)

~ 1 campaign every 2 years (CAMPAIGN / YEAR)

~ $100 / lb payload (BASE_COST / PAYLOAD)

~ 20 M lbs / campaign (PAYLOAD / CAMPAIGN)

Data sets supporting the values for the cost model parameters follow…

ESTIMATING OVERSEAS BASING COSTS

Available data places annual base operating costs at between $50M and $1B per year. This study assumed a basing cost of $100 million per overseas air base per year.

	Base	Location	[$M / year]
Overseas Bases	Ramstein	Germany	1000
	Other*	Germany	240
Domestic BRAC Closures**	Kelly	TX	174
	McClellan	CA	158
	Pease	NH	148
	Norton	CA	123
	Sawyer	MI	105
	Mather	CA	103
	Loring	ME	100
	Chanute	IL	98
	Castle	CA	88
	Eaker	AR	88
	George	CA	83
	England	LA	80
	Grissom	IN	80
	Carswell	TX	75
	Griffiss	NY	69
	Plattsburgh	NY	67
	Homestead	FL	61

Notes: * Average cost of 25 USAF and US Army bases in Germany.
** Reported numbers are final year cost savings for BRAC bases inflated to FY03 dollars

Sources: USAF BRAC; New York Time

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ESTIMATING OVERSEAS BASE USAGE

Each of the three most recent air wars used 10-20 overseas bases.

Kosovo

Tuzla	Bosnia
Istres	France
Geilenkirchen AB	Germany
Ramstein AB	Germany
Rhein Main AB	Germany
Spangdahlem AB	Germany
Ferihegy	Hungary
Taszar	Hungary
Aviano AB	Italy
Brindisi	Italy
Gioia Del Colle	Italy
Cervia-San Giorgio	Italy
NAS Sigonella	Italy
Moron AB	Spain
Balikesir	Turkey
Bandirma	Turkey
Incirlik	Turkey
RAF Brize Norton	UK
RAF Fairford	UK
RAF Lakenheath	UK
RAF Mildenhall	UK
RAF St Morgan	UK

Afghanistan

Diego Garcia	BIOT
Bourgas	Bulgaria
Souda Bay	Crete
Al Jaber AB	Kuwait
Ali Al Salem AB	Kuwait
Masirah AB	Oman
Seeb IAP	Oman
Thumrait AB	Oman
Al Udeid AB	Qatar
Constanta	Romania
Prince Sultan AB	Saudi Arabia
Incirlik AB	Turkey
Al Dhafra AB	UAE
RAF Fairford	UK
?	Jordan
?	Kuwait

Iraq

Bagram Airfield	Afghanistan
Muharraq Airfield	Bahrain
Diego Garcia	BIOT
Al Jaber AB	Kuwait
Ali Al Salem AB	Kuwait
Manas	Kyrgyzstan
Masirah AB	Oman
Seeb Int'l Airport	Oman
Thumrait AB	Oman
Jacobabad AB	Pakistan
Al Udeid AB	Qatar
Prince Sultan AB	Saudi Arabia
AL Dhafra AB	UAE

Identified approximately 40 unique overseas bases used since 1999…

Identified approximately 20 as USAF overseas airbases.

Sources: GlobalSecurity.Org

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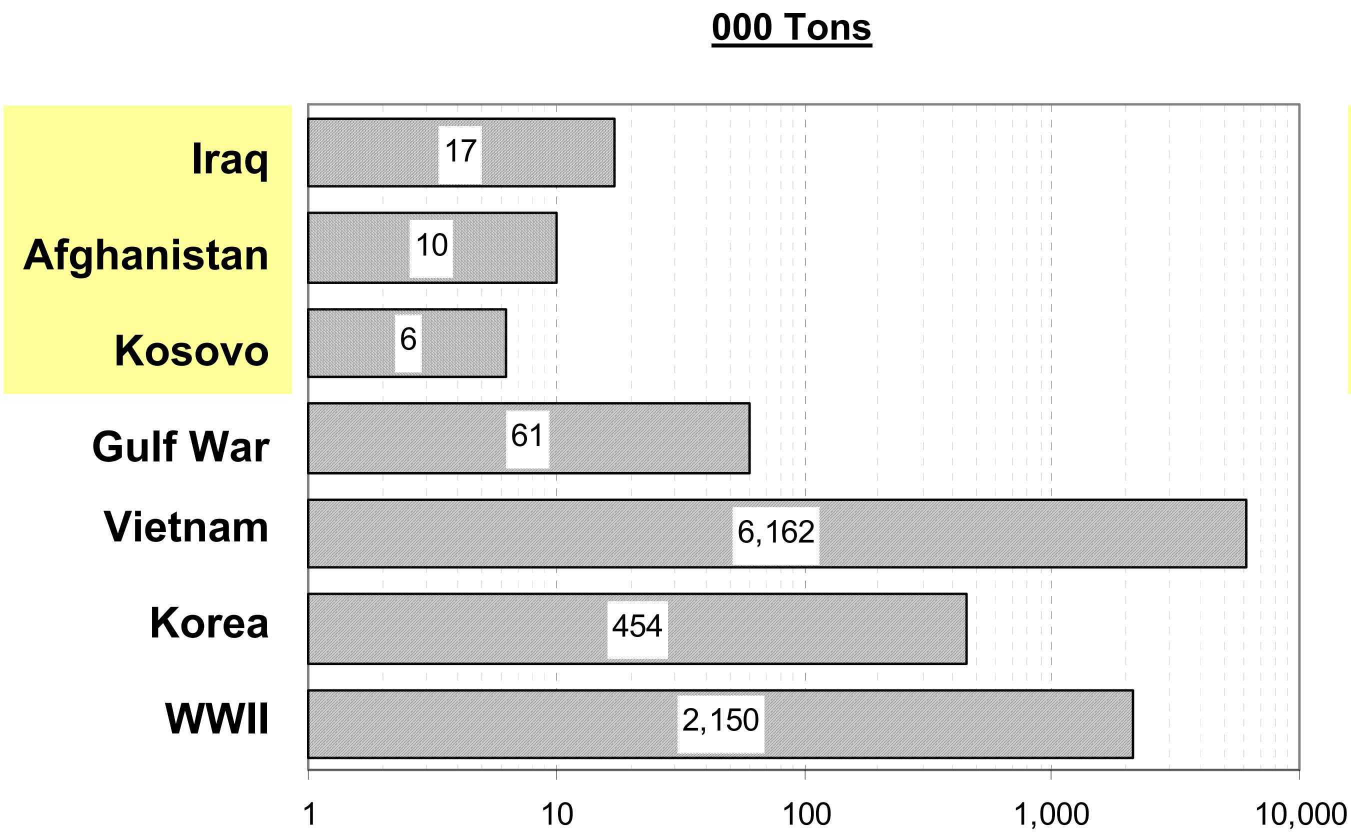
ESTIMATING CAMPAIGN INTENSITY

Approximately 5-15 thousand tons of ordnance were dropped during each of the three most recent air wars. This is a substantial decline from earlier wars.



	Months	000 Tons /Month
Iraq	1.0	17
Afghanistan	2.5	4
Kosovo	2.6	2.5
Gulf War	1.5	40
Vietnam	140	44
Korea	37	12
WWII	45	48

*Note log scale

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Sources: Globalsecurity.org, USAF “Iraq by the Numbers”

MODELING OVERSEAS DEPLOYMENT COSTS

Deployment costs are modeled as the cost to ferry a platform from CONUS to the campaign theater using aerial refueling. Deployment costs are unique to each platform, but the aggregate deployment cost can be estimated as follows:

Outbound and Inbound Ferry Cost | **Sortie Rate** | **Campaign Intensity**

$$\frac{FERRY\_COST}{PAYLOAD} \approx \underbrace{\left[\frac{FERRY\_COST}{PLATFORM}\right]}_{\text{Outbound and Inbound Ferry Cost}} \cdot \underbrace{\left[\frac{PLATFORMS}{CAMPAIGN}\right]}_{\text{Sortie Rate}} \Big/ \underbrace{\left[\frac{PAYLOAD}{CAMPAIGN}\right]}_{\text{Campaign Intensity}}$$

~ $4 / lb payload

~ $200K / ferry

~ 400 strike A/C / campaign

~ 20 M lbs / campaign

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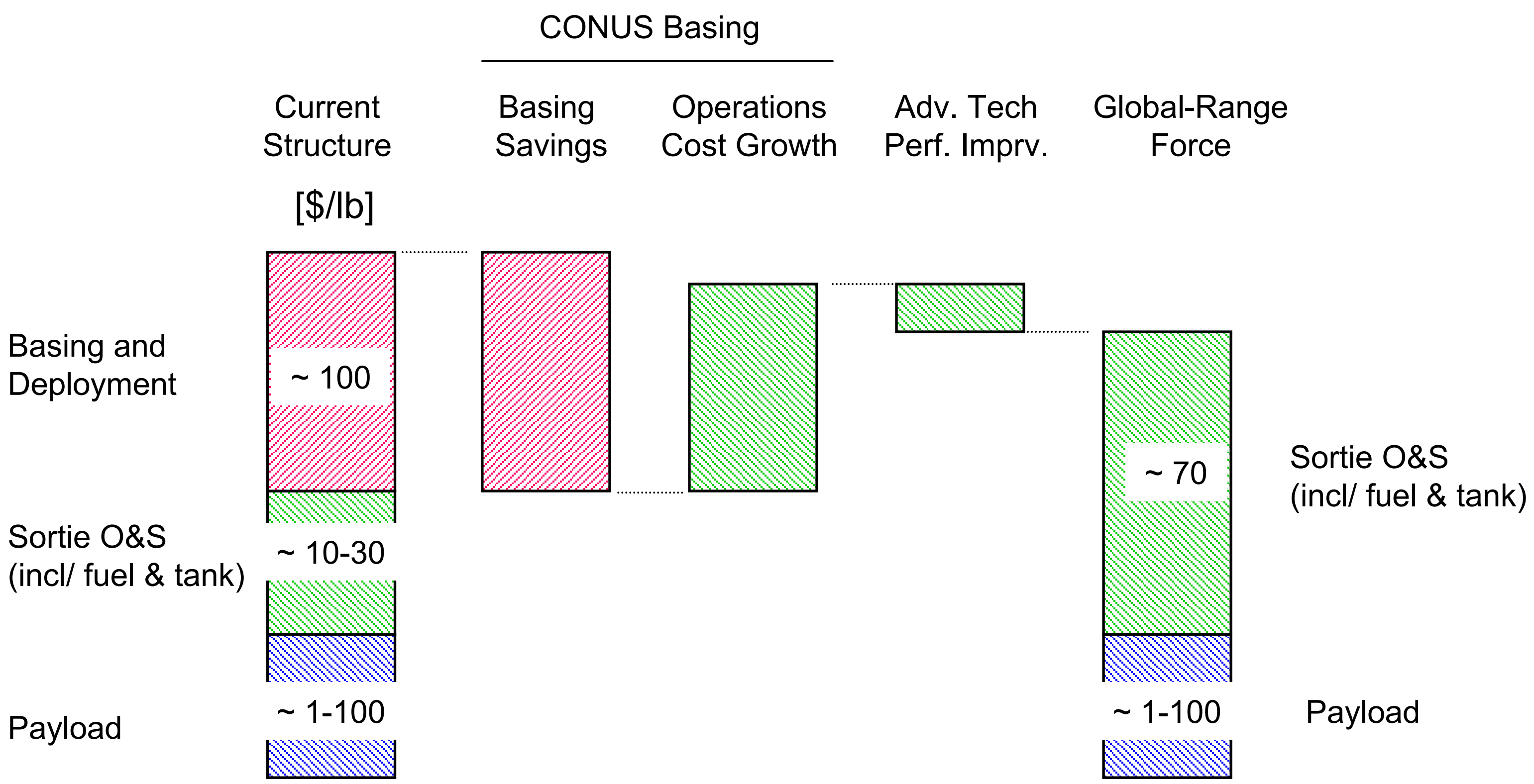
CONCLUSIONS

COST OF AF INFRASTRUCTURE

Global-range missions substitute operational costs for overseas-basing costs, leading to an overall cost savings.



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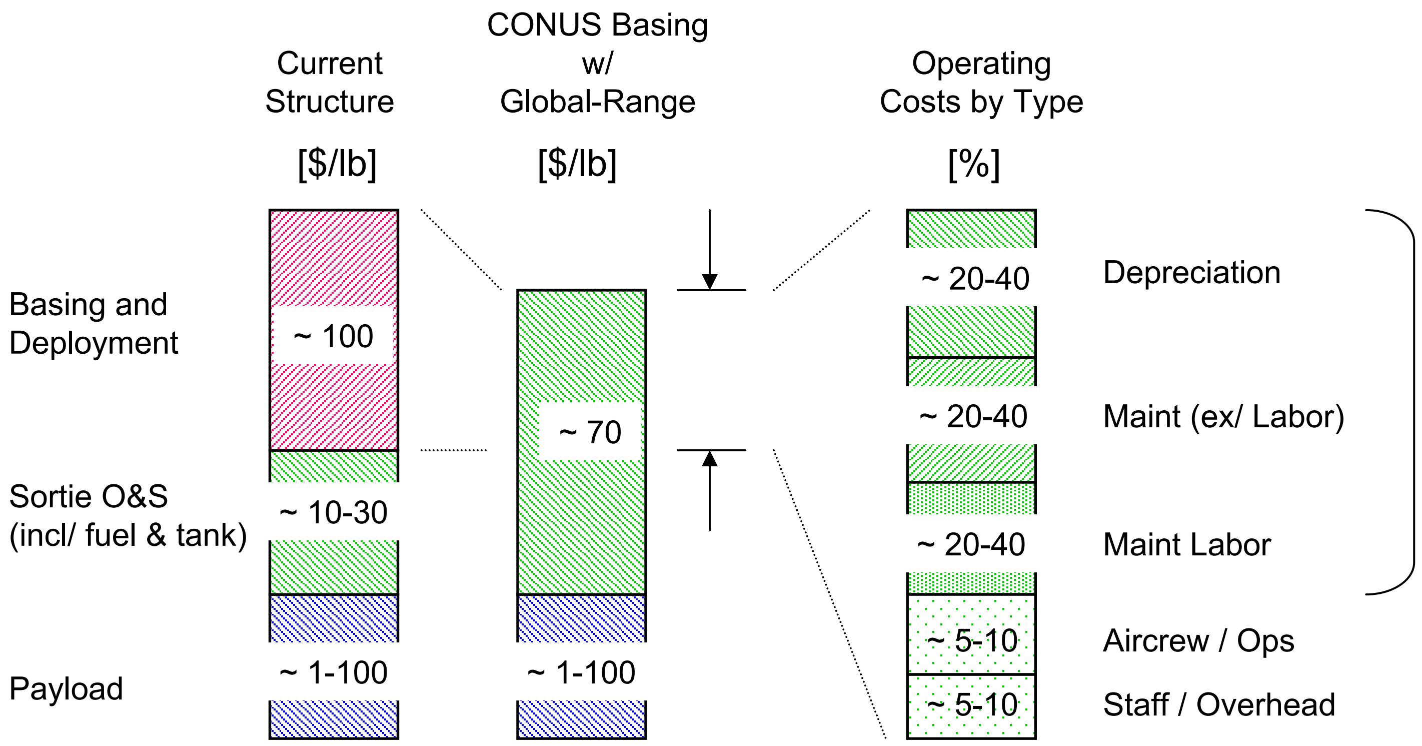
GLOBAL RANGE OPENS A NEW MARKET

A global-range force replaces overseas-basing costs with operations and support costs...

… and many of these O&S costs can be captured as revenue by platform manufacturers.



A global-range force opens a new market for platform suppliers, allowing them to 'grab' a revenue stream currently owned by construction firms, property managers, etc.

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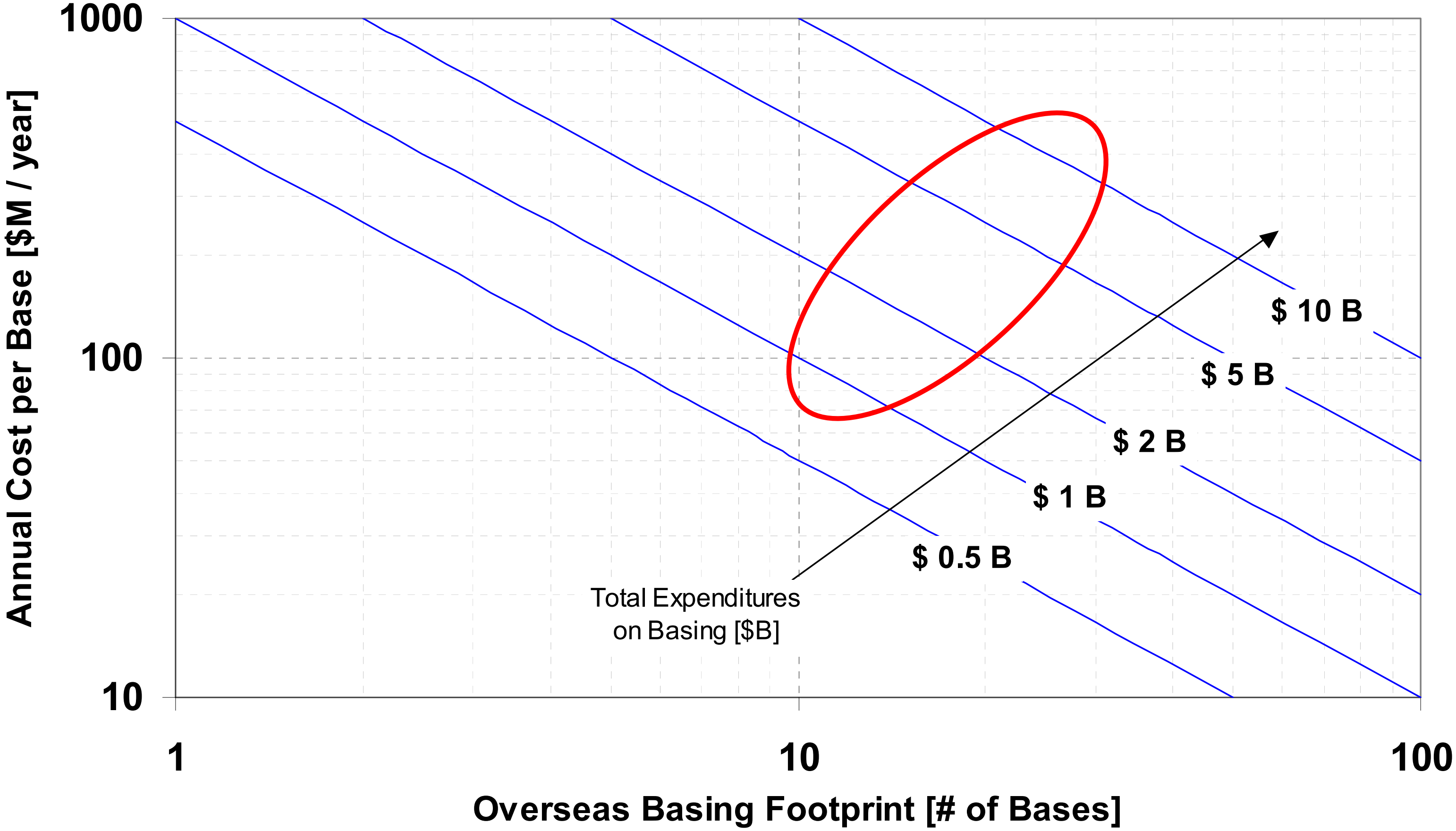
THE OVERSEAS-BASING REVENUE STREAM IS LARGE

Depending on estimates of footprint and base operating cost, the estimated total expenditure on overseas basing, and, hence, the capture-able revenue stream, is in the range of $1B to $10B.



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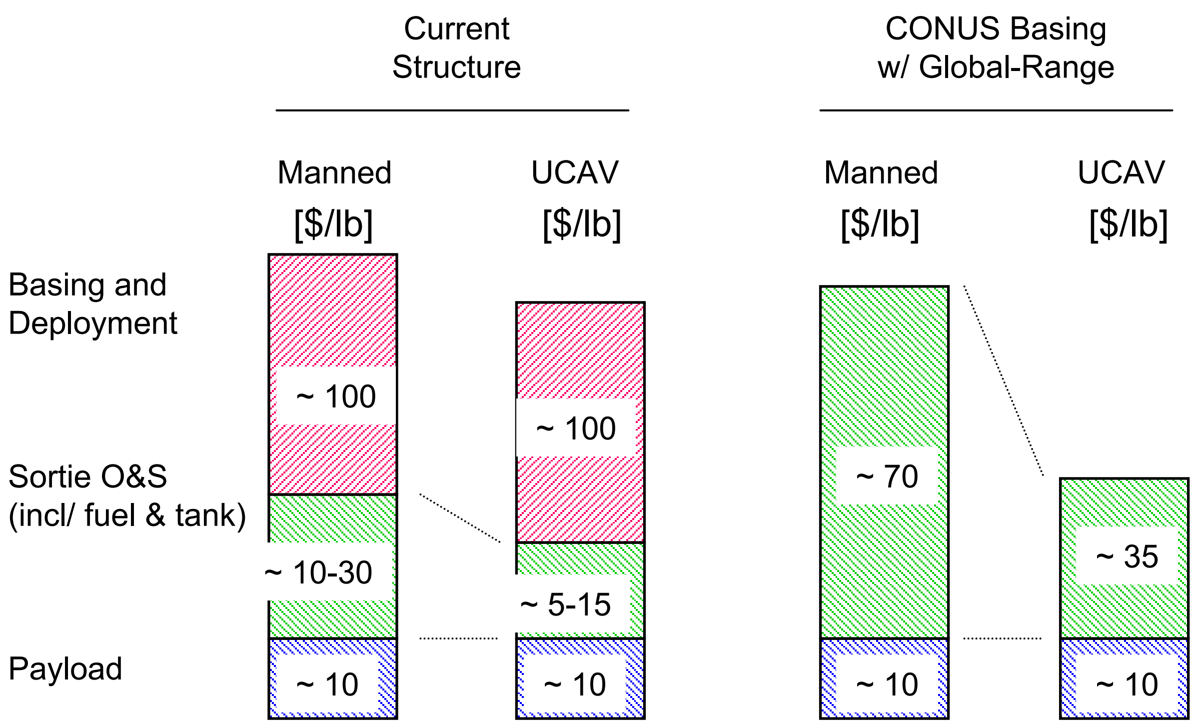
GLOBAL RANGE ENHANCES UCAV COST SAVINGS

With overseas basing, the O&S cost savings from UCAV operations lead to only a small overall cost savings because basing costs dominate...

… while CONUS basing makes O&S the dominate cost, amplifying UCAV savings.



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PRELIMINARY CONCLUSIONS

Preliminary results suggest that a CONUS-based, global range strike platform would be cost-competitive with the current basing concept.

- **Model suggests a valuable trade-off between range and basing costs**
  - Modeled basing costs ~ 10x larger than direct mission costs (O&S + Fuel)
  - Basing model excluded base startup and non-platform AEF deployment costs.
  - Mission costs model is comprehensive, including indirect tanker costs.
  - With current platform performance levels, global range looks break-even.

- **Future UCAV platforms make global range more attractive.**
  - Limited peacetime flying can reduce O&S costs by and order of magnitude.
  - Uninhabited vehicle can allow for new size and geometry concepts that allow optimization of a long-range platform.

NEXT STEPS

- **Refine model of USAF infrastructure costs.**
  - Verify platform performance and O&S cost parameters.
  - Improve “resolution” of basing cost model: (1) AEF deployment, (2) startup
  - Expand analysis to loitering platforms (recce, CAP, CAS)
  - Expand analysis to airlift platforms. Include airlift as indirect cost in deployment cost model.

- **Estimate hypothetical cost and performance for a global range platform..**
  - Poll “expert opinion” for likely operating and support costs.
  - Develop a preliminary layout; estimate performance parameters.
  - Use cost model to predict cost benefit of new technologies