RAND PROJECT AIR FORCE

Air Combat Past, Present and Future

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August 2008

Air superiority is foundation for ALL US conventional military operations

- **Freedom from attack/freedom to attack**
  - **Enables rapid, secure deployment and sustainment flows**
  - **Protects forces and supplies once deployed**
  - **Enables persistent ISR and strike operations against enemy fielded forces**
  - **Enables strategic attack operations**
- **Without air superiority US Joint CONOPs unravel**

Legacy of Desert Storm

- **For the USAF:**
  - **Concept of aerial warfare validated**
  - **Key elements:**
    - **Fighter-centric combat power generated from close, secure bases**
    - **BVR air to air combat**
    - **Stealth**
    - **PGMs**
  - **Force modernization decisions focused on refining key elements**
  - **Numerical superiority and US strategic/operational initiative received less emphasis**

- **For USAF Opponents:**
- **Effective ground and air operations in face of USAF capabilities problematic or impossible**
- **Needed *concepts* and *systems* to:**
  - **Disrupt sortie generation and/or deny basing**
  - **Counter BVR missiles**
  - **Counter stealth**
  - **Counter PGMs**

Russia, China, India and others developed concepts to counter USAF key elements by mid- to late-1990s – systems to support them now IOC and proliferating

Current Concept for Air Superiority Requires Secure Bases, Stealth and BVR

- **Close and secure bases necessary to generate sufficient sorties**

- **US fighters must dominate battle from long range to counter enemy quantitative advantage**
  - **This requires**
    - **"First View, First Shot, First Kill"**
    - **Superior situational awareness (stealth & sensors)**
    - **Minimal vulnerability (stealth)**
    - **Lethal Beyond Visual Range (BVR) missiles**

Should we assume we will meet these requirements in a battle with a capable enemy?

What Happens if Key Assumptions Fail?

- **“Will we have access to secure, close bases?”**
- **“Will Stealth work as advertised?”**
- **“Will Beyond Visual Range (BVR) missiles work as advertised?”**
- **“Can we fight outnumbered and win?”**

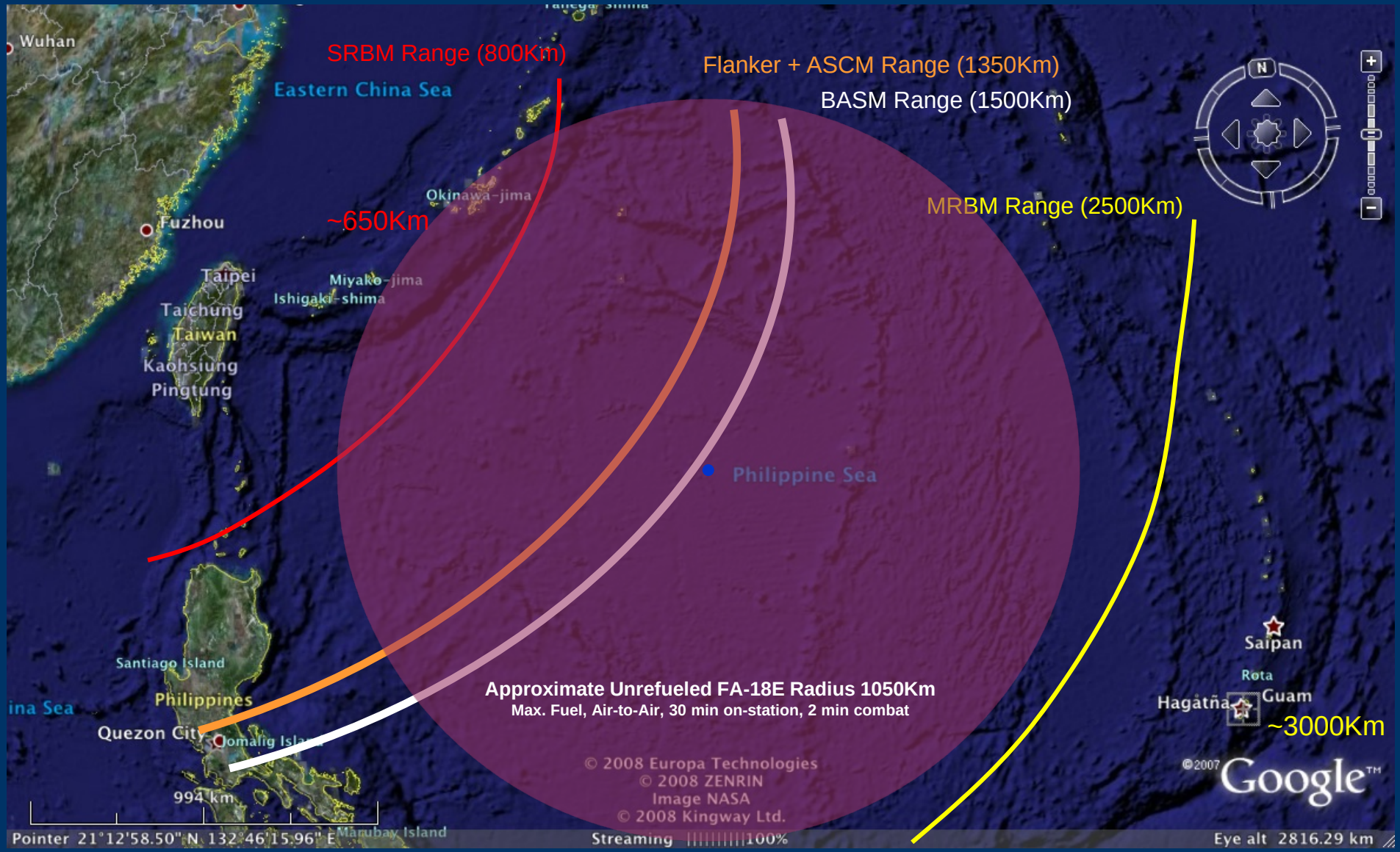
U.S. air bases and aircraft carriers are icons of American power

- Land and sea-based air power essential to American way of war
- Efficient generation of large number of sorties critical to accomplish operational objectives
- Widely seen as exemplars of U.S. technological prowess and military dominance
- Key instruments of statecraft
  - Deterrence
  - Reassurance of allies
  - Presence
  - Foundation for rapid response and power projection

Chinese anti-access efforts seek to deny U.S. ability to operate efficiently from nearby bases or seas

- **Chinese threats to Carrier Strike Groups include**
  - **Anti-Ship Ballistic Missiles (ASBM)**
  - **Diesel electric (and soon nuclear) submarines equipped with torpedoes and SS-N-22 and SS-N-27 ASCMs**
  - **Fighters and bombers carrying ASCMs and HARMs**
  - **Patrol craft with ASCMs**
- **Chinese threats to air bases include**
  - **SRBM and IRBMs**
  - **Land and air-launched cruise missiles**
- ***Large, sophisticated Chinese air, naval and missile force can mass against small number of U.S. carriers and air bases in WESTPAC***

Geography and Land-Based Threat Ranges



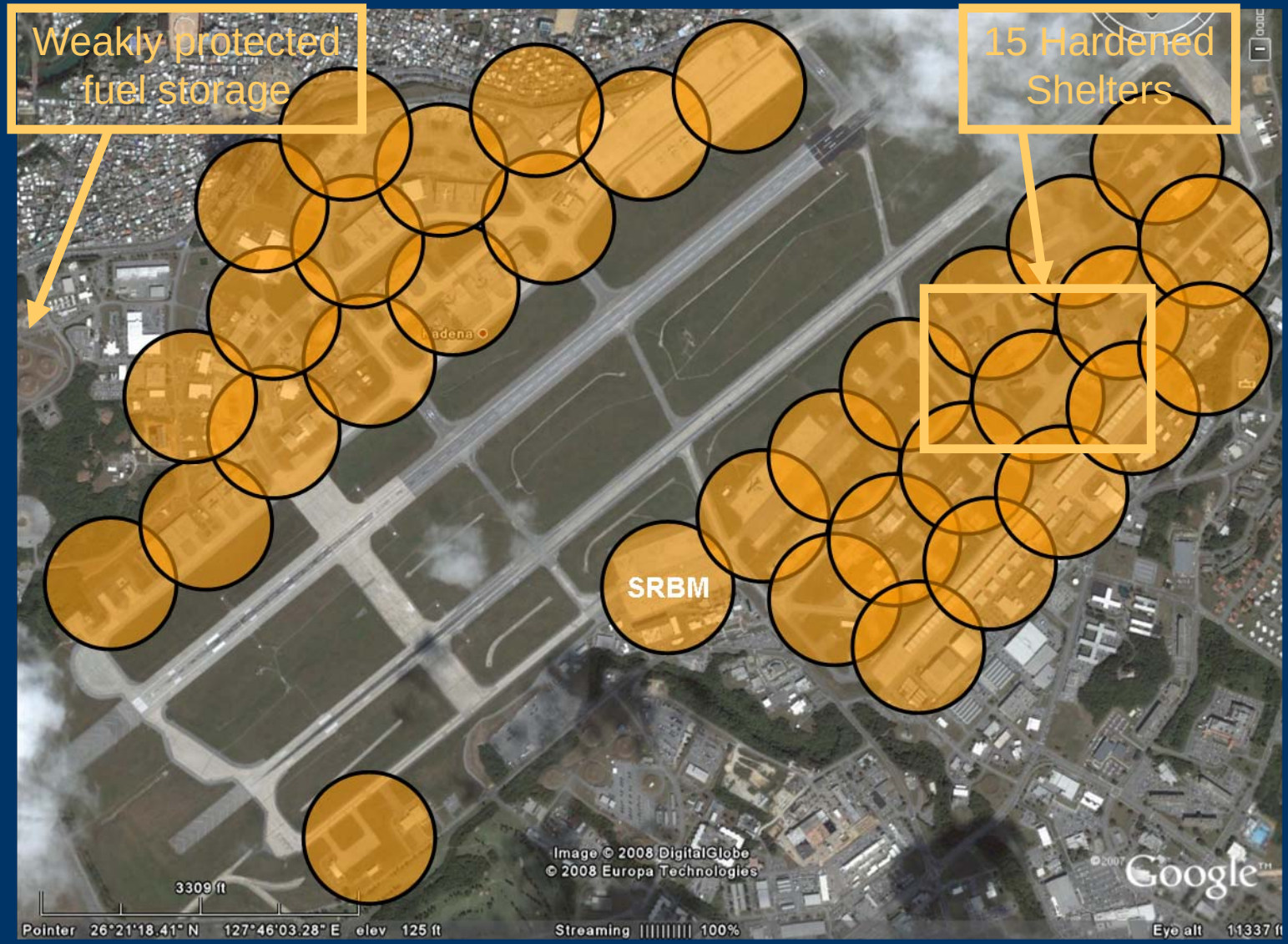
Air Superiority Concept Requires Secure Bases Close to Operational Area

- **Without secure close bases sortie rates rapidly decline**
- **USAF has enjoyed secure close bases since end of Cold War BUT…**
- **Experience of post-Cold War era is anomalous**
  - **WW II: USAAF bases in Europe and Pacific subject to major air attacks as late 1945**
    - **Europe: *Operation Bodenplatte* on morning of January 1, 1945**
      - **~800 German fighters attacked 17 allied airfields**
      - **500 + Allied aircraft damaged or destroyed**
  - **1950s and 1960s: Bases attacked by enemy ground and/or air forces in Korea and Vietnam**
  - **1970s and 1980s: Assumed USAFE bases were subject to attack**

Operation *Bodenplatte*

Is the era of close secure basing coming to an end?

34 missiles with submunition warhead could cover all parking ramps at Kadena



Attack like this could damage, destroy or strand 75 percent of aircraft based at Kadena

Many PLAAF bases are significantly harder than Kadena

Many PLAAF bases are significantly harder than Kadena

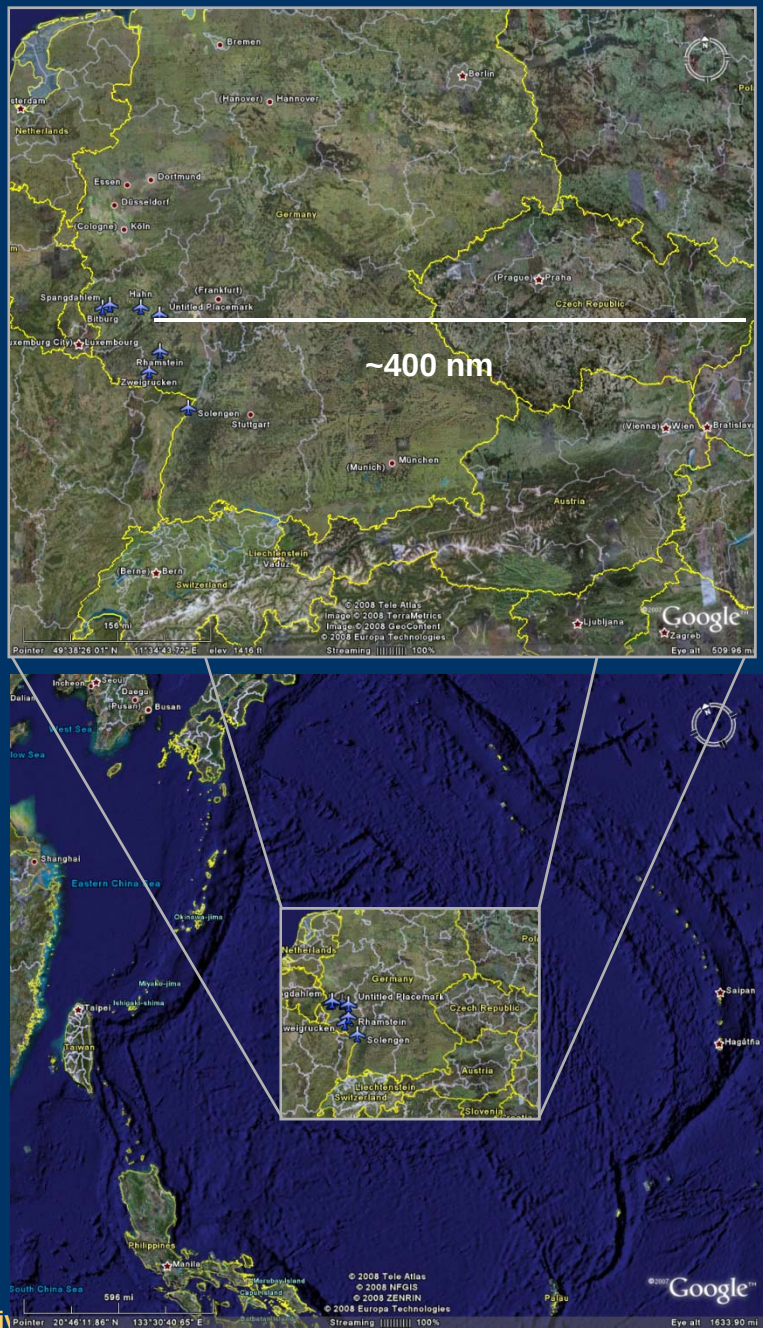
Some PLAAF bases have super-hard underground hangers

USAF has only one base within 500 nm of Taiwan Strait

- **USAF fighter operations most efficient within 500 nm of battle area**
  - **ODS Fighter Distance to Baghdad ~556 nm**
  - **OAF Fighter distance to Belgrade ~366 nm**
- **PLA has 27 bases within 500 nm of Taiwan Strait - - USAF just one**

Central front battle space fits within Philippine Sea

- Current and planned CAF fighter fleet range*payload optimized for Cold War Central Front battle
- Scale of western Pacific theater is 3 to 4 times as large as Central Front battlespace
- Operating current and planned CAF fighters in western Pacific will result in:
  - Low sortie rates/reduced combat power
  - Huge tanker demand



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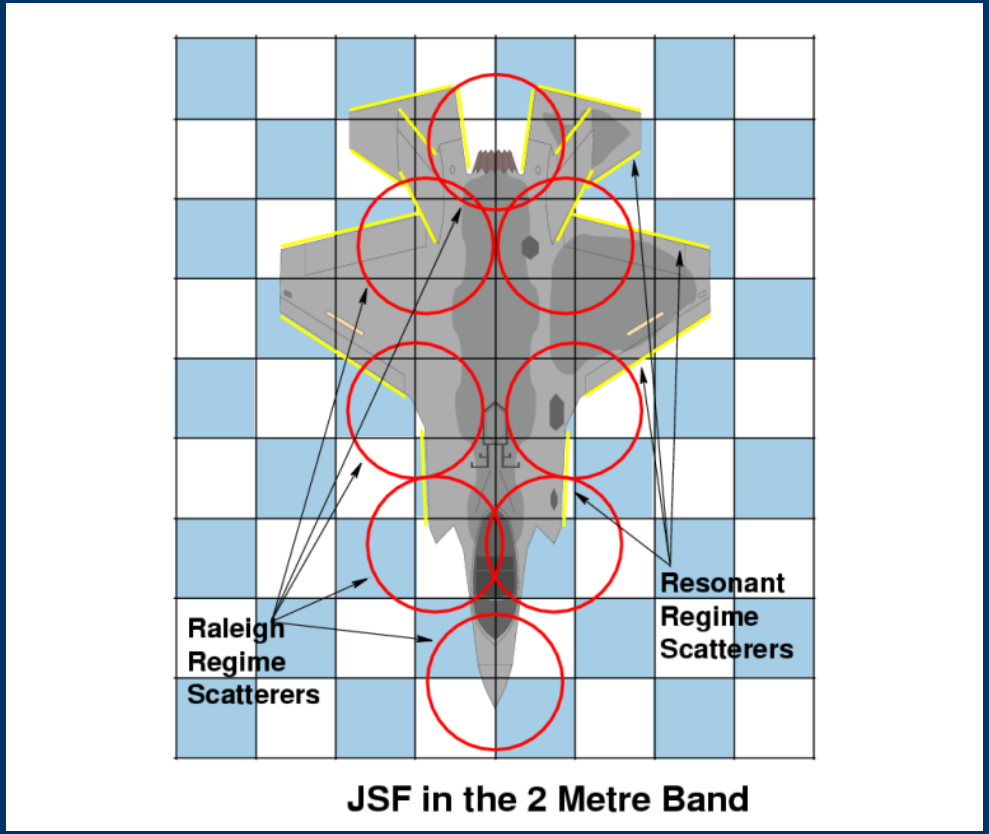
What if stealth is countered?

- **Unclassified treatment of stealth**
  - **Looks at fundamentals of sensor and platform physics**
  - **Examines implications of recent and ongoing counter-stealth sensor developments by potential adversaries**

How robust is Stealth against emerging sensor technologies?

- **Stealthy fighters are not invisible - - just difficult to detect at certain radar frequencies**
  - **Optimized against X-Band engagement radars**
- **VHF radars have wavelengths in the 1-3 meter range**
  - **F-22 ~ 19 meters long, 13.5 meters wide**
  - **F-35 ~15 meters long, 11.5 meters wide**
- **Key fighter dimensions about 4 to 10 times VHF radar frequencies – heart of Raleigh scattering region**



Courtesy Air Power Australia @ http://www.ausairpower.net/

How robust is Stealth against emerging sensor technologies?

- **Nebo SVU VHF Digital AESA – in service and for sale**
  - Being integrated into SA-20/21 units
  - Most mobile VHF acquisition radar ever built
  - Digital AESA design allows
    - accurate bearing measurement ~ 0.5 degrees
    - Distance measurement ~200 meters
    - Altitude measurement

    +- 2,700 ft @ 60 nm

    +- 6.500 ft @ 150 nm
  - Error box of the Nebo SVU ***MAY*** be small enough to allow mid-course updates for long range SAMs or AAMs
    - More than adequate for GCI or network-enhanced situation awareness for fighters
- **Chinese CETC Y-27 very similar**
- **Advanced IR sensors also of increasing concern as counter-stealth technology**
  - More on this later

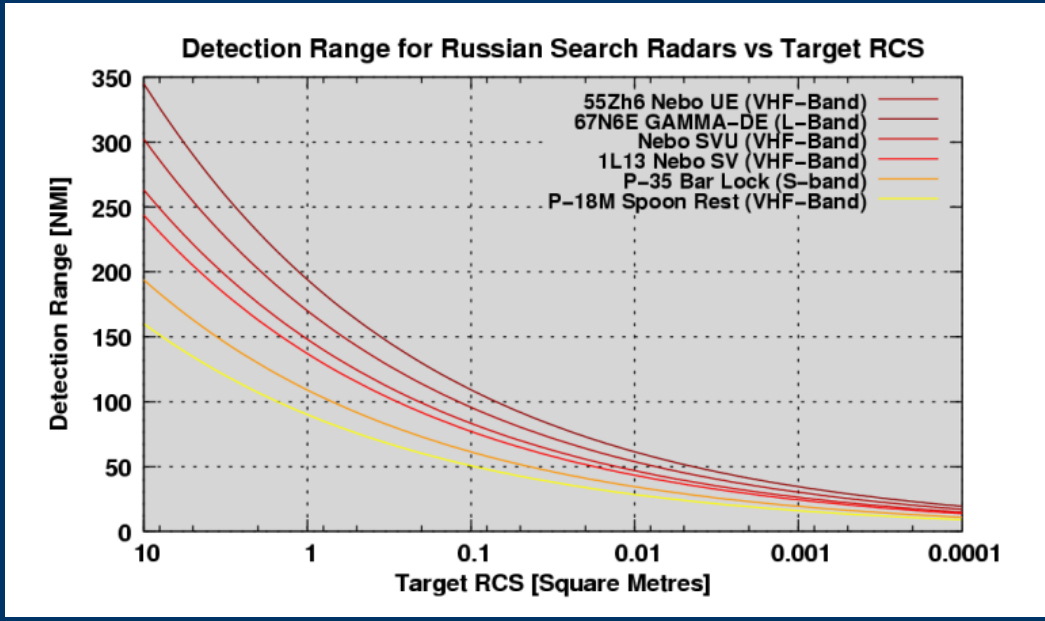
Courtesy Air Power Australia @ http://www.ausairpower.net/

Russian Nebo SVU

Courtesy Air Power Australia @ http://www.ausairpower.net/

Courtesy: Carlo Kopp

Chinese CETC JY-27



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"Will the BVR missiles work?"

- **U.S. went into Vietnam relying on AIM-7 Sparrow as main air-to-air missile**
  - **Pre-war estimated Pk: 0.70**
  - **Demonstrated Pk: *0.08***
  - **MiG 100 times likelier to make it to gun range than expected**

AIM-7

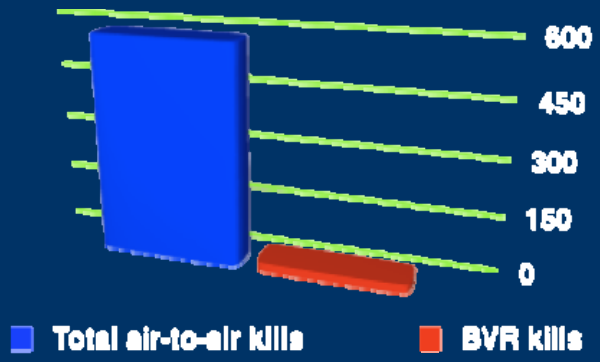
Déjà Vu All Over Again? The BVR Puzzle

- **U.S. went into Vietnam relying on AIM-7 as main air-to-air missile**
  - **Pre-war estimated Pk: 0.70**
  - **Demonstrated Pk: *0.08***
  - **MiG 100 times likelier to make it to close fight than expected**
- **Current AIM-120 has demonstrated ~0.59 pK in combat to date**
  - **17 missiles fired for 10 kills**
  - **What does that really mean?**

AIM-7 AIM-120

The History of BVR Employment

- Since the advent of BVR missiles, 588 air-to-air kills have been recorded by BVR-equipped forces
  - 24 have been BVR*



*Note: Russian sources claim 4 additional unconfirmed BVR kills by SAF in 1982

http://en.wikipedia.org/wiki/Mikoyan-Gurevich_MiG-23

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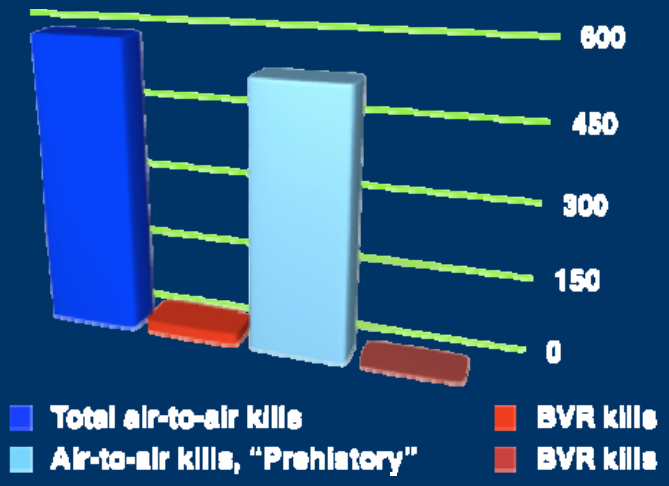

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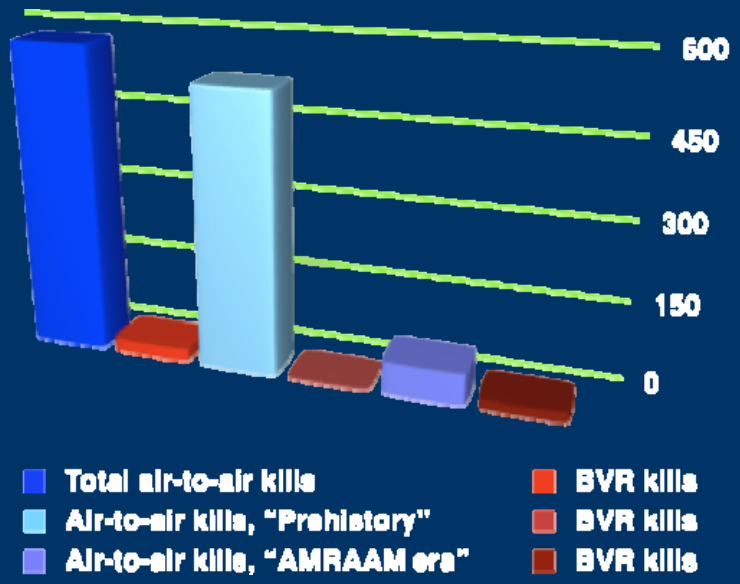

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- Since 1991, 20 of 61 kills have been BVR
- In "AMRAAM era," BVR's "share" of kills has *increased 43 fold*

This glass seems more than half full!

But How Applicable Is This Track Record?

Date	Unit	Aircraft	Pilot	Weapon	Victim	Country	Fired
27-Dec-92	USAF	F-16D		AIM-120A	MiG-25PD	IrAF	1
17-Jan-93	USAF	F-16C		AIM-120A	MiG-29B	IrAF	1
28-Feb-94	86FS/526FW	F-16C 89-2137	B.Wright	AIM-120A	J-21	RVRS (Pesic KIA)	1
14-Apr-94	53FS/52FW	F-15C	E.Wickson	AIM-120A	UH-60A	US Army	1
24-Mar-99	322 sqn KLu	F-16A/MLU J-063	P.Tankink	AIM-120A	MiG-29 18106	127.lpe/JRViPVO (Milutinovic OK)	1
24-Mar-99	493EFS/48FW	F-15C 86-0169	C.Rodriguez	AIM-120C	MiG-29 18112	127.lpe/JRViPVO (Arizanov OK)	1
24-Mar-99	493EFS/48FW	F-15C 86-0159	M.Shower	AIM-120C	MiG-29 18111	127.lpe/JRViPVO (Nikolic OK)	3
26-Mar-99	493EFS/48FW	F-15C 86-156	J.Hwang	AIM-120C	MiG-29 18113	127.lpe/JRViPVO (Radosavljevic KIA)	1
26-Mar-99	493EFS/48FW	F-15C 86-156	J.Hwang	AIM-120C	MiG-29 18114	127.lpe/JRViPVO (Peric OK)	2
4-May-99	78EFS/20FW	F-16C 91-0353	M.Geczy	AIM-120C	MiG-29 18109	127.lpe/JRViPVO (Pavlovic KIA)	1

- **U.S. has recorded ten AIM-120 kills**
  - **Four *not* Beyond Visual Range**
  - **Fired 13 missiles to achieve 6 BVR kills Pk = 0.46***
  - **Iraqi MiGs were fleeing and non-maneuvering**
  - **Serb J-21 had no radar or Electronic Countermeasures (ECM)**
  - **US Army UH-60 not expecting attack; no radar or ECM**
  - **Serb MiG-29 FULCRUMS had inoperative radars**
  - **No reports of ECM use by any victim**
  - **No victim had comparable BVR weapon**
  - **Fights involved numerical parity or US numerical superiority**
- **None of these likely to apply to fight with Chinese FLANKERS**

How much degradation of BVR performance can our air-to-air concept tolerate?

The Measure – Countermeasure Game (1 of 3)

- Early AIM-9s designed for use against non-maneuvering targets from rear aspect
- NVA MiGs countered AIM-9s by “rotating the vulnerable cone”
  - Test Pk ~ 0.65 fell to 0.15 in combat in Vietnam
- Post Vietnam US developed all-aspect, highly maneuverable AIM-9L

The Measure – Countermeasure Game (2 of 3)

- AIM-9L entered production in US in 1978 and in Europe in 1982
- UK Harriers equipped with US made AIM-9Ls for Falklands conflict in Spring of 1982
- Increased maneuverability and all aspect capability effectively negated Argentine traditional anti-missile tactics
  - 26 AIM-9L fired
  - 19 kills achieved
  - Pk = 0.73


http://www.targetlock.org.uk/seaharrier/invincible.jpg


http://content.answers.com/main/content/wp/en/b/ba/Mirage_IIIEA_...PAB.jpg

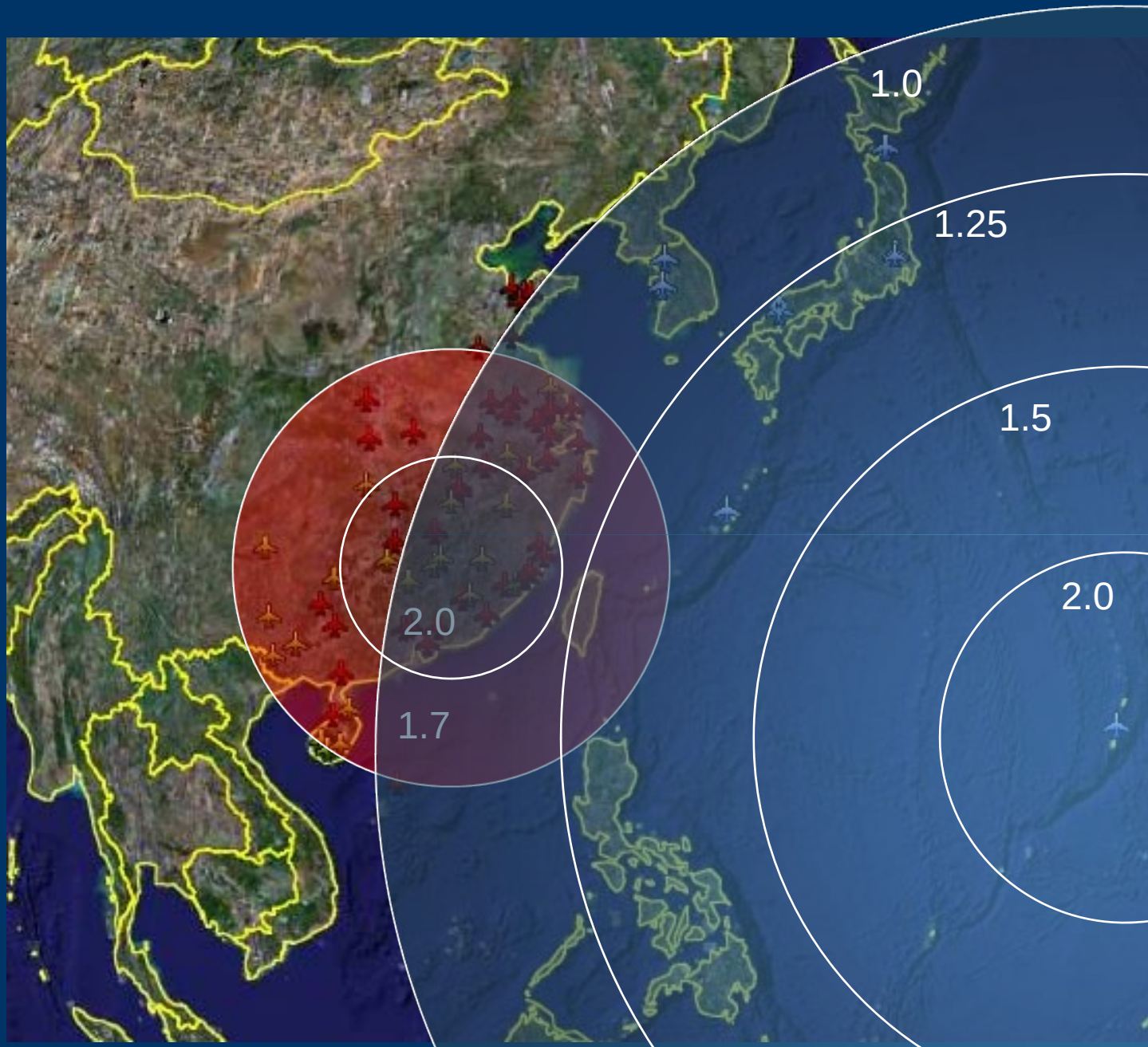
The Measure – Countermeasure Game (3 of 3)

- Mid-1980s many nations develop and deploy IR decoy flares in response to demonstrated IR missile lethality
- Late-1980s USAF developed improved AIM-9M
  - AIM-9L with “flair rejection” circuits designed to counter decoy flares
- BUT, flares much more effective than anticipated
  - USAF,USN and USMC fired 48 AIM-9M in Desert Storm and achieved only 11 kills
  - Pk reduced to just 0.23 – Much closer to Vietnam era performance than 1982 performance

Bottom Line – There is a significant “last move” advantage in this game AND it applies in both the radar and IR realms

The Numbers Game

- Assumes all fighters remain on station 1.25 hours
- PLA maintenance 80 percent as efficient as USAF maintenance



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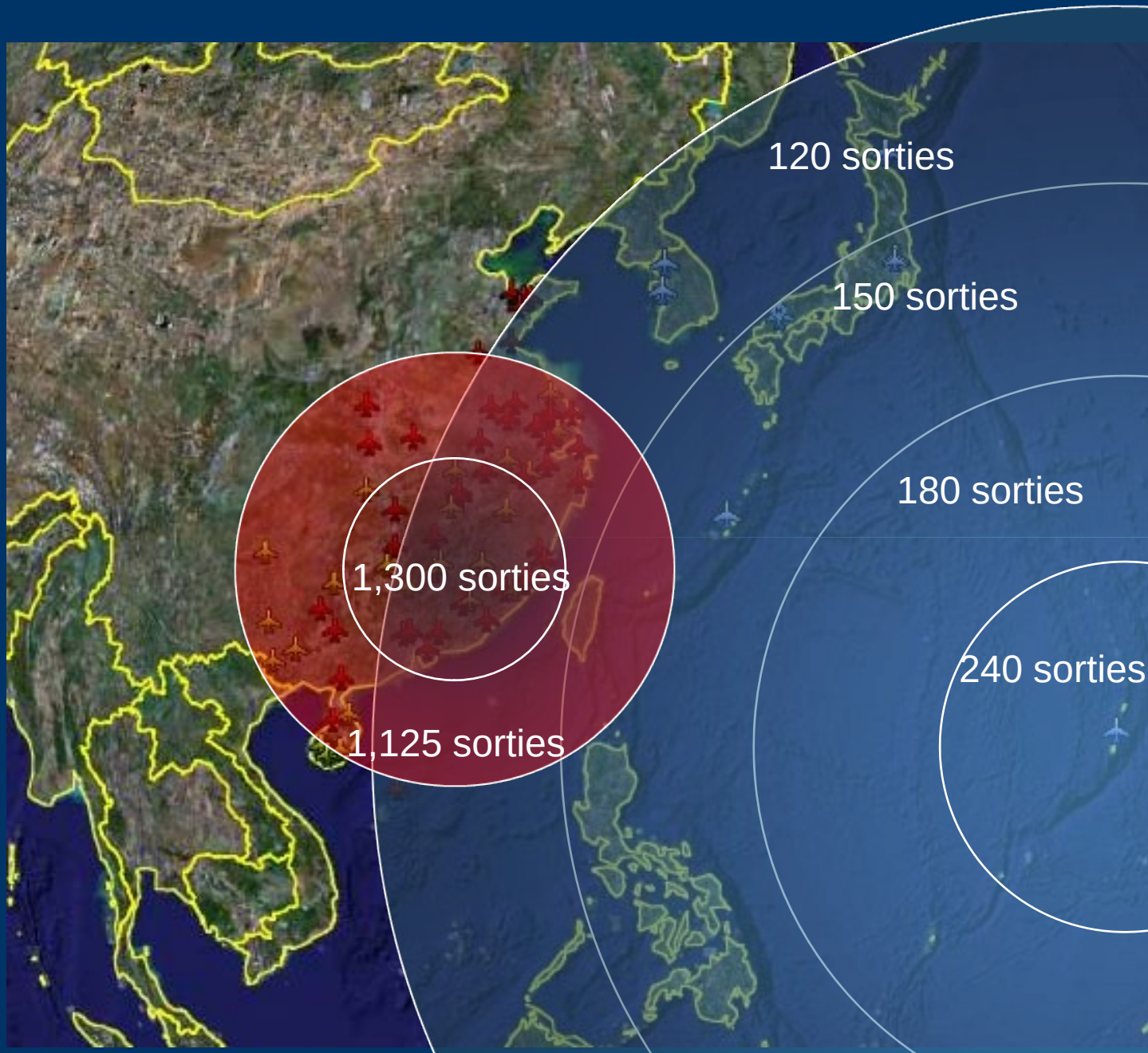
The Numbers Game

- Assume entire F-22 PMAI deployed to Andersen
- Sorties over Taiwan Strait about 138 per day vs. over 1,300 for PLA



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The Numbers Game

- If a conflict develops between China and the US over Taiwan then:
  - Can't predict who will have had the last move in the measure-countermeasure game
  - China could enjoy a 3:1 edge in fighters *if* we can fly from Kadena – about 10:1 if forced to operate from Andersen
- Overcoming these odds requires qualitative superiority of 9:1 or 100:1
- Such qualitative superiority is *extremely* difficult to achieve against a comparable power
  - Neither the USAAF/RAF nor Luftwaffe ever achieved this level of dominance on a large scale at any time during WW II
  - The USAF did not achieve it in Korea 1950-53
  - IAF achieved it in 1982
  - Coalition forces may have achieved it in Operation Desert Storm
    - Enjoyed qualitative ***AND*** quantitative superiority

How Much Can Quality Compensate for Quantity? (1 of 2)

- JV 44 most qualitatively dominant fighter unit of all time
  - Equipped with revolutionary Me-262
    - Vastly superior to all other single seat fighters in terms of:
      - Speed – 24 percent faster than USAAF escorts
        - Reduced reaction time from first detection by up to 62 percent
      - Rate of climb: 70 percent faster than USAAF escorts
      - Firepower: More than double other German fighters and 7 times P-51D
    - Experienced pilots could use surprise and vertical maneuvers to dominate any engagement
  - Led and staffed with cream of Luftwaffe aircrew including virtually all surviving *experten* (aces)
    - 25+ aces out of ~50 pilots
    - Top 6 aces had 1100+ kills
    - Next 11 averaged 50+ kills


http://www.kheichhorn.de/assets/images/me262_3.jpg


Adolf Galland
(104 kills)


Johannes Steinhoff
(176 kills)


Heinrich Bar
(221 kills)


Gerhard Barkhorn
(301 kills)

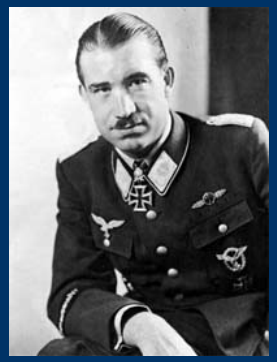

Walter Krupinski
(197 kills)


Günther Lützow
(110 kills)

How Much Can Quality Compensate for Quantity? (2 of 2)

- JV 44 qualitative edge increased per sortie lethality by over 20 times vs. typical Luftwaffe units…
- …BUT Pk for USAAF fighters almost identical vs. jets in 1945 or props in early 1944
- Based on kills, losses and force ratio, JV 44 qualitative edge was 9:1
  - If you believe Lanchester square criteria apply maximum break even force ratio for JV 44 was about 3:1
- *What is it for the F-22? F-35?*


http://www.kheichhorn.de/assets/images/me262_3.jpg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Summary of Air-to-Air Uncertainty

- If modern BVR weapons live up to expectations AND stealth is not countered AND we have secure close bases our air-to-air CONOP is sound
  - But, history suggests there is a limit of about 3:1 where quality can no longer compensate for superior enemy numbers
- If BVR is substantially less effective than anticipated, OR stealth is countered OR we lack secure close bases, we lose some (much?) of our edge
- Best case for U.S.: *Our* BVR works, *theirs* doesn't; stealth works, they don't have it; we have secure close bases
  - *Imprudent to rely on this*

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Air Combat PPF 34

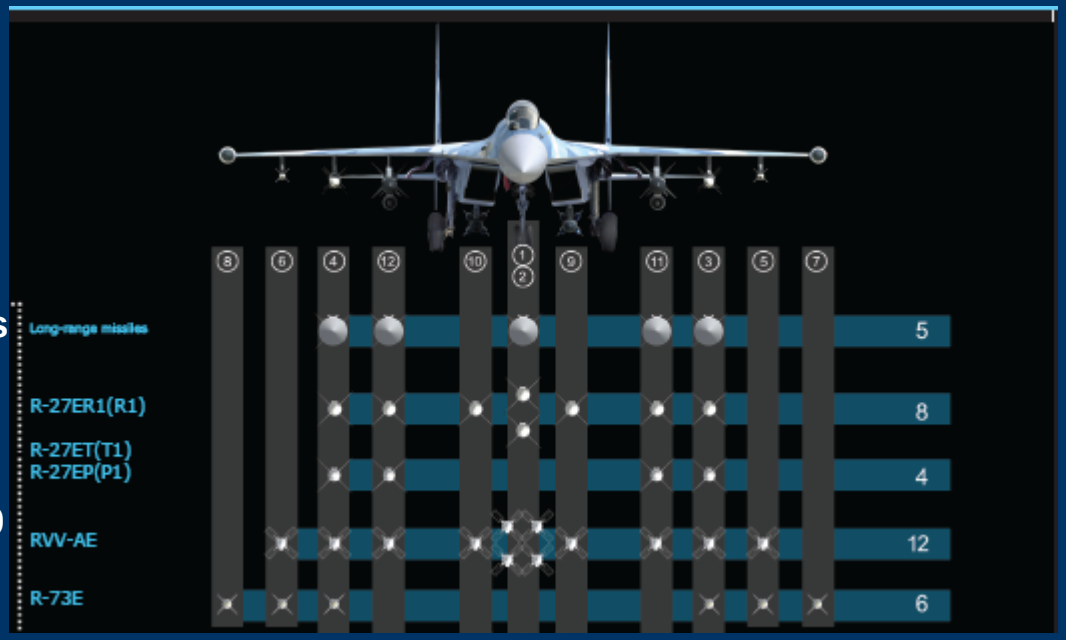
Important Things to Recall

- **Russian and Chinese fighter CONOPs likely rely on:**
  - **Numbers**
  - **Firepower**
  - **Sensor diversity (on aircraft and weapons)**
  - **Advanced ECM (e.g. DRFM "cross-eye" jammers, towed decoys, etc.)**
  - **Greater ability to absorb attrition**

- **Globalization has increased the speed of technology diffusion compared to the Cold War**
  - **Our lead in sensors and electronics is both smaller and shorter lived than in the past**
  - **Technologies developed for the computer, television, medical imaging, telescope, and wireless network industries can be *directly* applied to fighter sensors and weapon systems**

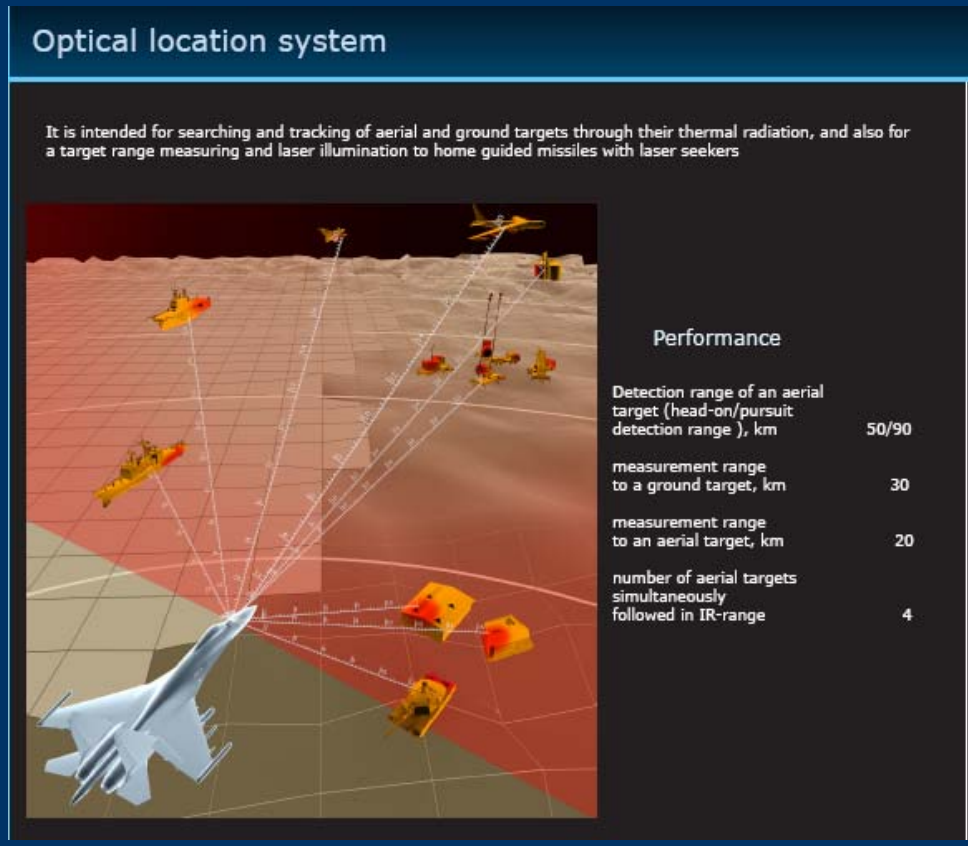
“It’s not your father’s Flanker”

- Flanker is a big, tough Russian aircraft
  - Large internal fuel capacity
  - Large load carrying capability
  - Modular/evolutionary design philosophy makes upgrades relatively easy and inexpensive
- Latest Flankers (e.g. Su-35BM) have large, diverse air-to-air missile loadout
  - Standard loadouts include options for up to 14 AAMs
    - Current Chinese SU-27/30/J-11 carry “only” 10
    - Likely most will be upgraded to SU-35BM standard by 2020
  - Most missiles come in active radar and IR versions
  - Long range anti-LD/HD missiles have advertised range of up to 215 nm
- Standard Russian and Chinese tactics call for multiple mixed-seeker missile salvos
  - Controls even include a switch to automatically launch salvo with correct sequence and timing



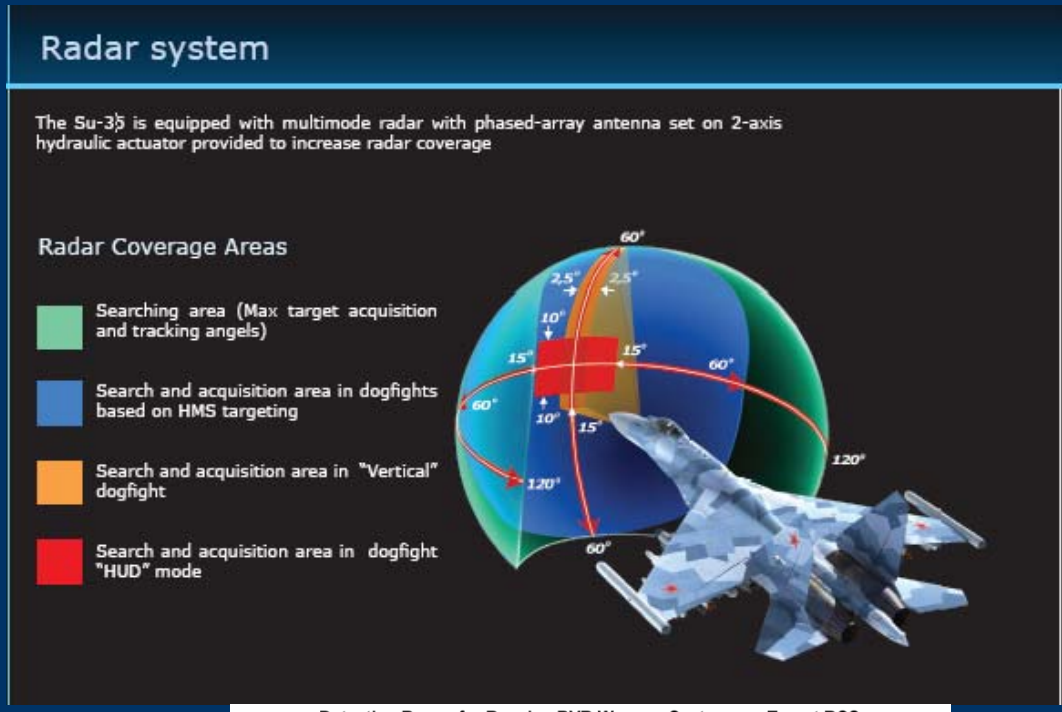
“It’s not your father’s Flanker”

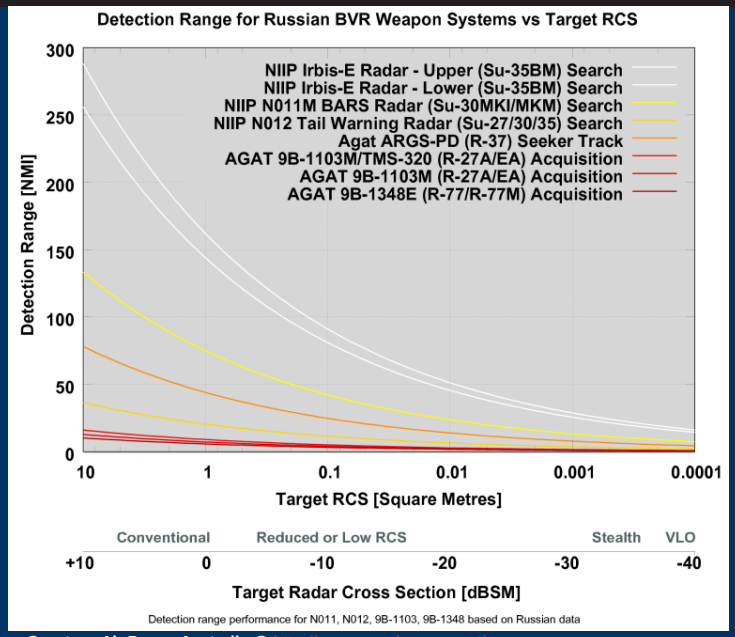
- All Flankers carry an Infra-Red Search and Track System (IRSTS) – existing US fighters do not
  - Latest version is OLS-35
  - Capable of tracking typical fighter target head-on at 50 km (27 nm) tail on at 90 km (50 nm)
  - +- 90 degree azimuth coverage
  - +60 deg, - 15 deg elevation coverage
- Fighter supercruising at Mach 1.7 generates shock cones with stagnation temperature of 188 deg. F
  - Should increase detection range about 10 percent to 30 nm head-on
- AMRAAM launches have large, unique thermal signature
  - Could allow early detection of F-22 and missile launch warning at up to 50+ nm
- AMRAAM at Mach 4 generates 1200 deg. F shock cone – missile could be tracked at up to 45+ nm
- Advanced IRSTS integrating commercially available Quantum Well Infrared Photodetector (QWIP) imaging technology likely available within 5 years and will greatly increase performance
  - Typhoon already has one with unclassified detection range for subsonic head-on airborne targets of 50 nm



“It’s not your father’s Flanker”

- Flanker radar performance has doubled over the past 8 years
- Likely to continue to increase as Russian and Chinese AESA designs are introduced over the next decade
- By 2020 even very stealthy targets likely detectable by Flanker radars at 25+ nm





Courtesy Air Power Australia @ http://www.ausairpower.net/

"It's not your father's Flanker"

- **Survivability feature include:**
  - **Foam-filled, inerted fuel tanks**
  - **Titanium tube engine mounts that serve as main rear structure AND armor for engines**
  - **Redundant systems**
  - **Superb ejection seat**
- **4 of 5 Serb MiG-29 pilots shot down by AIM-120s in 1999 survived – Flanker pilots likely to do better if hit**

2020 Example: Scope and Assumptions

- Scope: air-to-air battle circa-2020 considered in isolation
  - Surface-to-air elements or air-to-surface elements excluded
    - Taiwanese SAMs and possible USN AEGIS ships operating near Taiwan excluded
    - Exception is PLA Ground Controlled Intercept radar
  - But, adding these is likely to make the USAF task MORE difficult
    - Taiwan SAMs don't play – likely killed early by TBMs anyway
    - PLA SAMs don't play either but they are much more likely to survive initial exchanges

- For this example US air superiority goals assumed to be:
  1. Limit damage to Taiwan by providing effective continuous air defense
  2. Enable air attacks against any possible invasion fleet
  3. Protect ISR and tanker aircraft orbits

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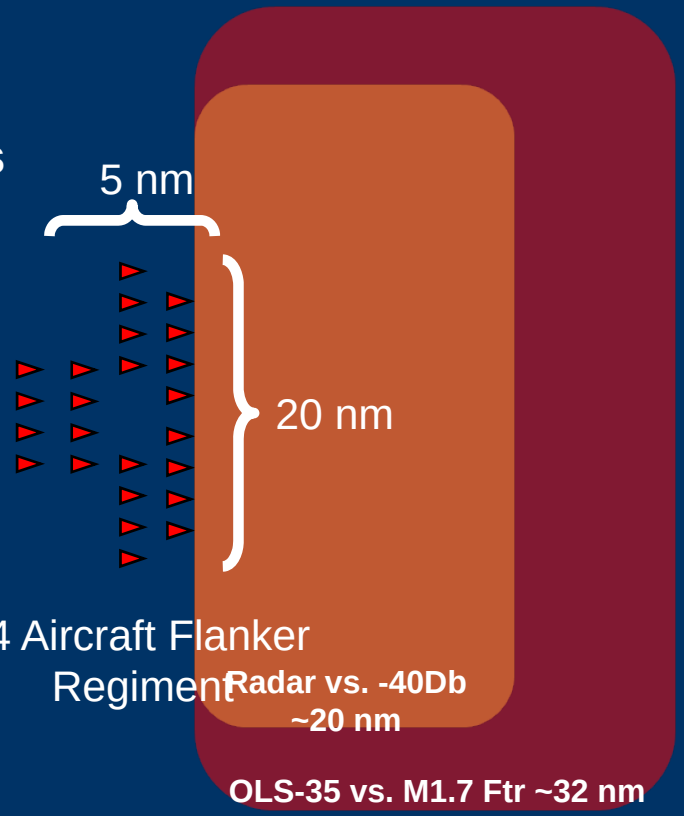
2020 Employment Example

- PLAAF training and operational art not as sophisticated as USAF
- PLAAF could employ simple regiment formations
  - 1.5 nm to 2 nm spacing line abreast – easy to fly and maintain visually
  - Allows robust mutual support with IRSTS and radar
- A 24-aircraft Flanker regiment can lift 16 anti-LD/HD missiles, 240 AA-12/PL-12 BVR missiles and 48 AA-11 WVR missiles
  - Total missiles: 304 AAMs
  - 24 F-22s lift only 192 AAMs
  - 24 F-35s lift only 96 AAMs



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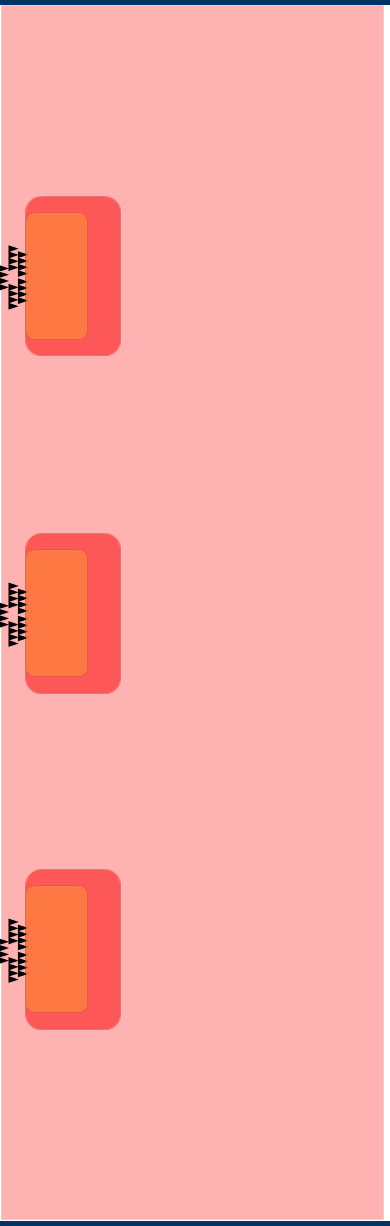
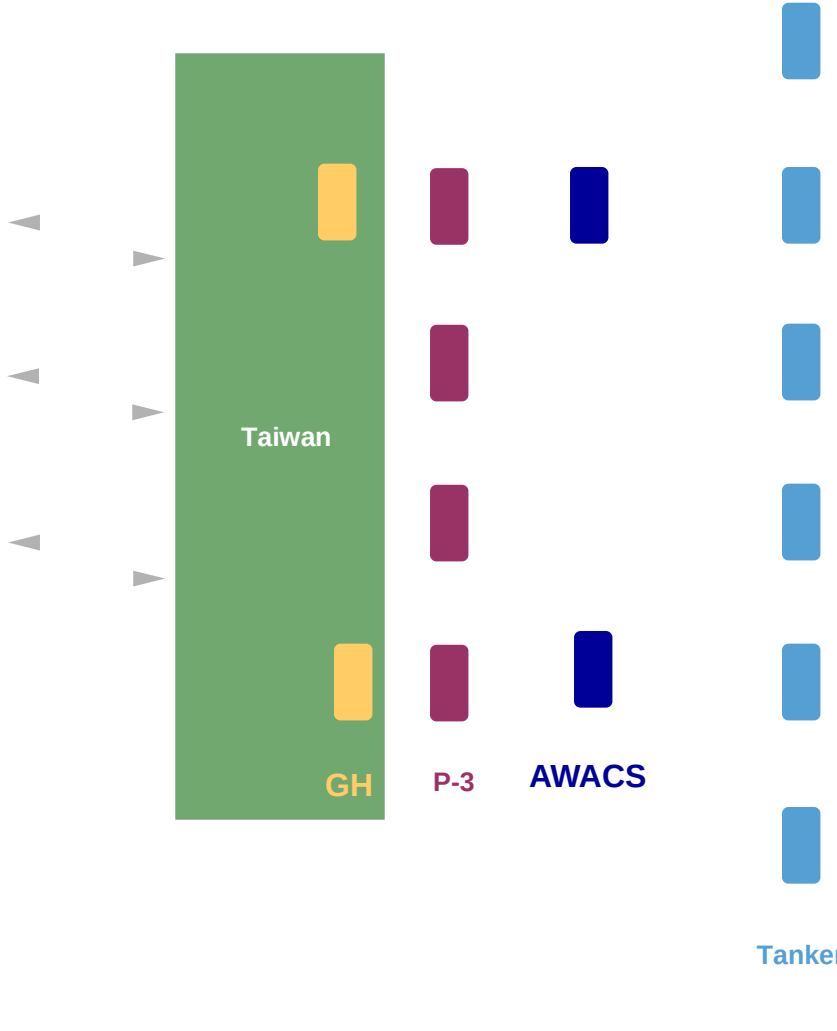
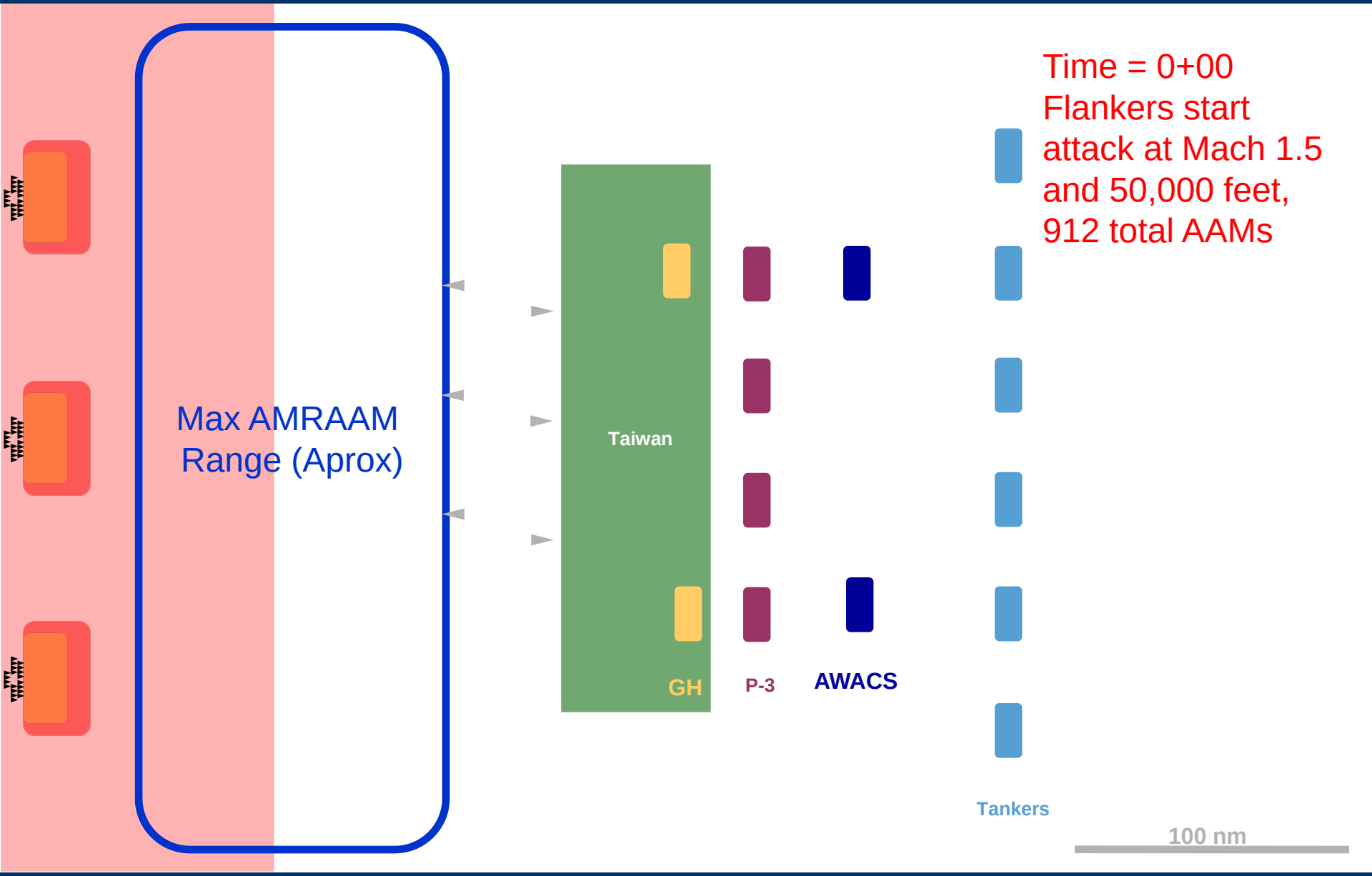




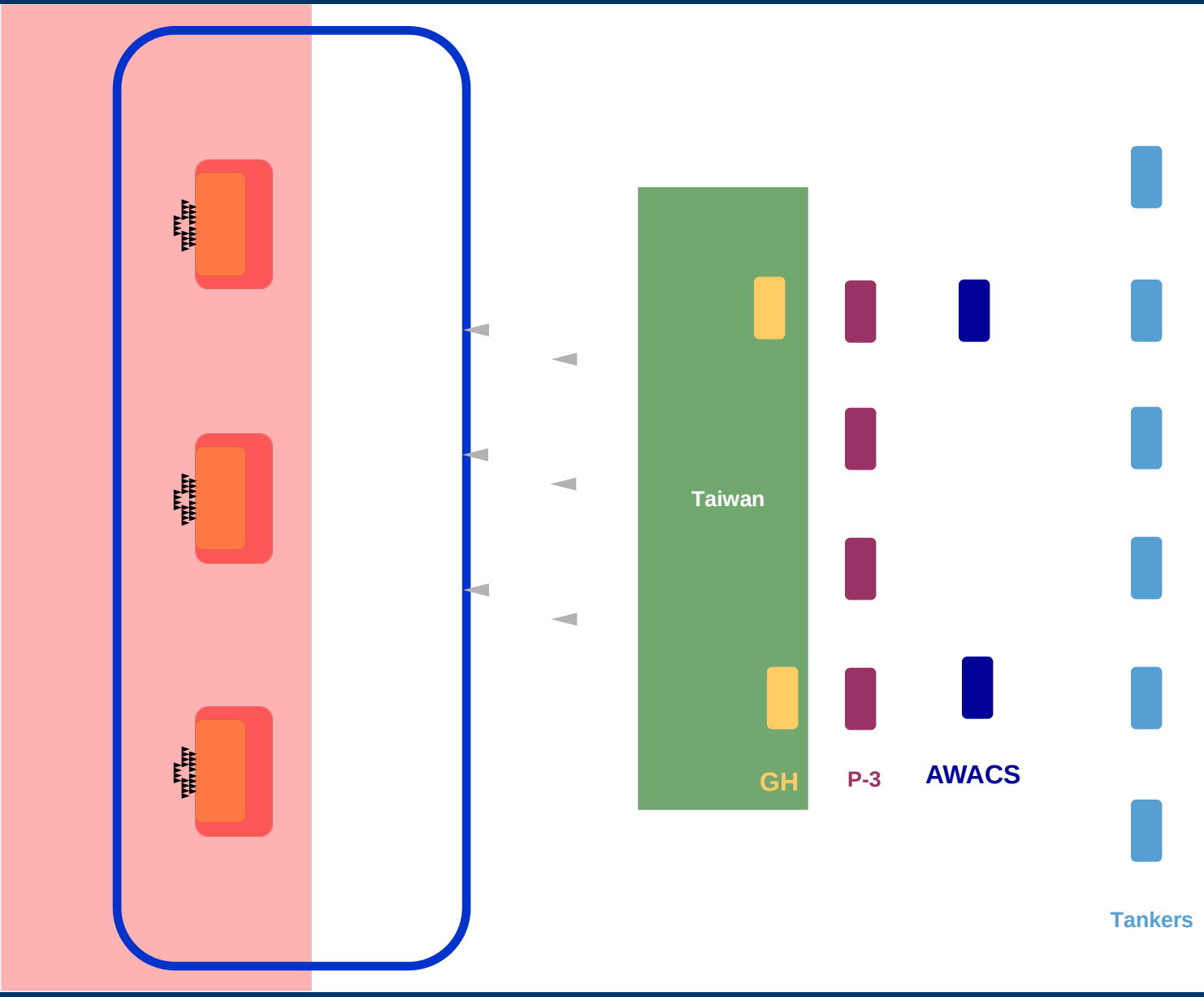
T= 0+00: Three Flanker regiments begin attack on USAF aircraft defending Taiwan

- Max continuous F-22s on station from Andersen is 6 - - total AAMs 48

2020 Employment Example



2020 Employment Example



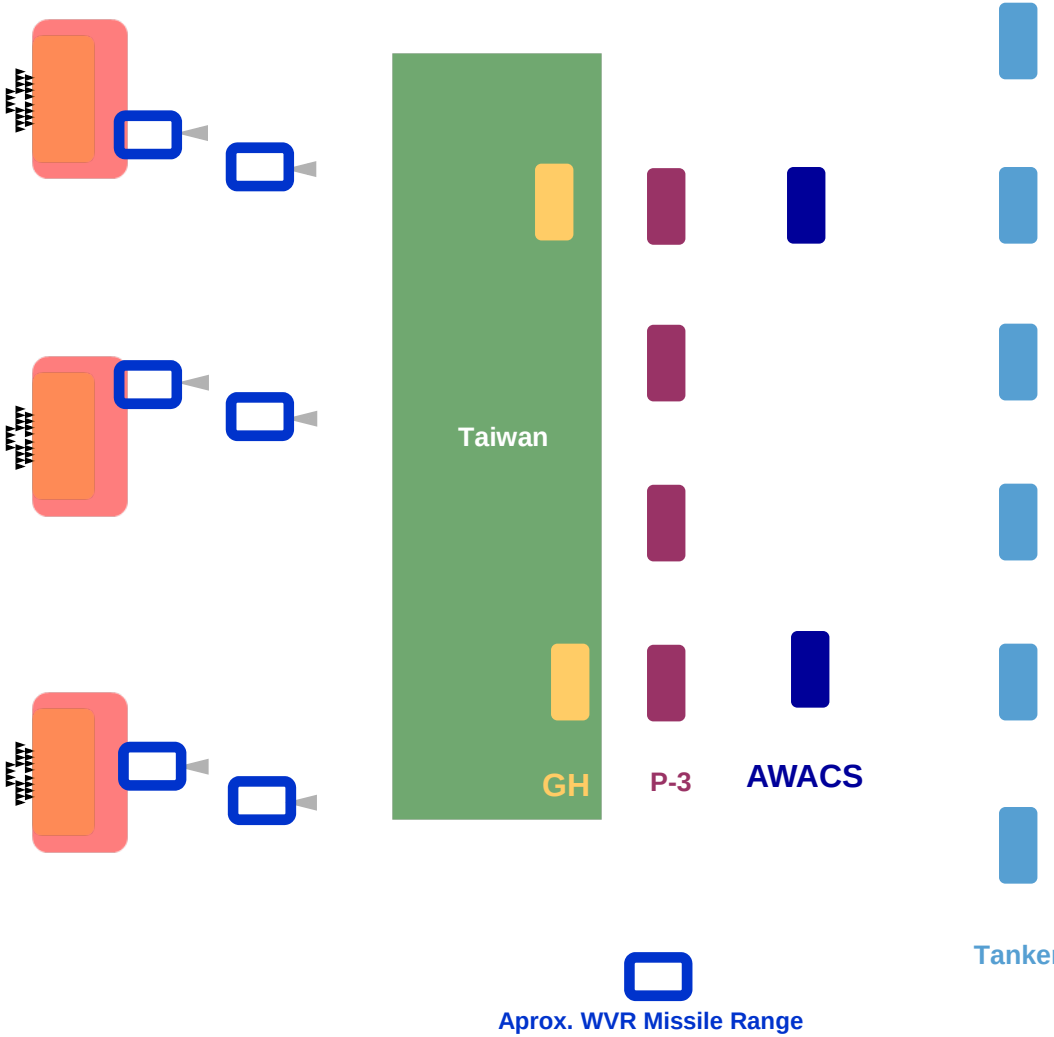
Time = 3+30 to 4+30

- 6 F-22s fire 36 AMRAAMs at 36 Flankers
  - 12 AIM-9s remaining

Time = 5+15 to 6+15

- 36 Flankers destroyed by AMRAAMs (assume 1.0 Pk)
  - 408 AAMs remaining

2020 Employment Example

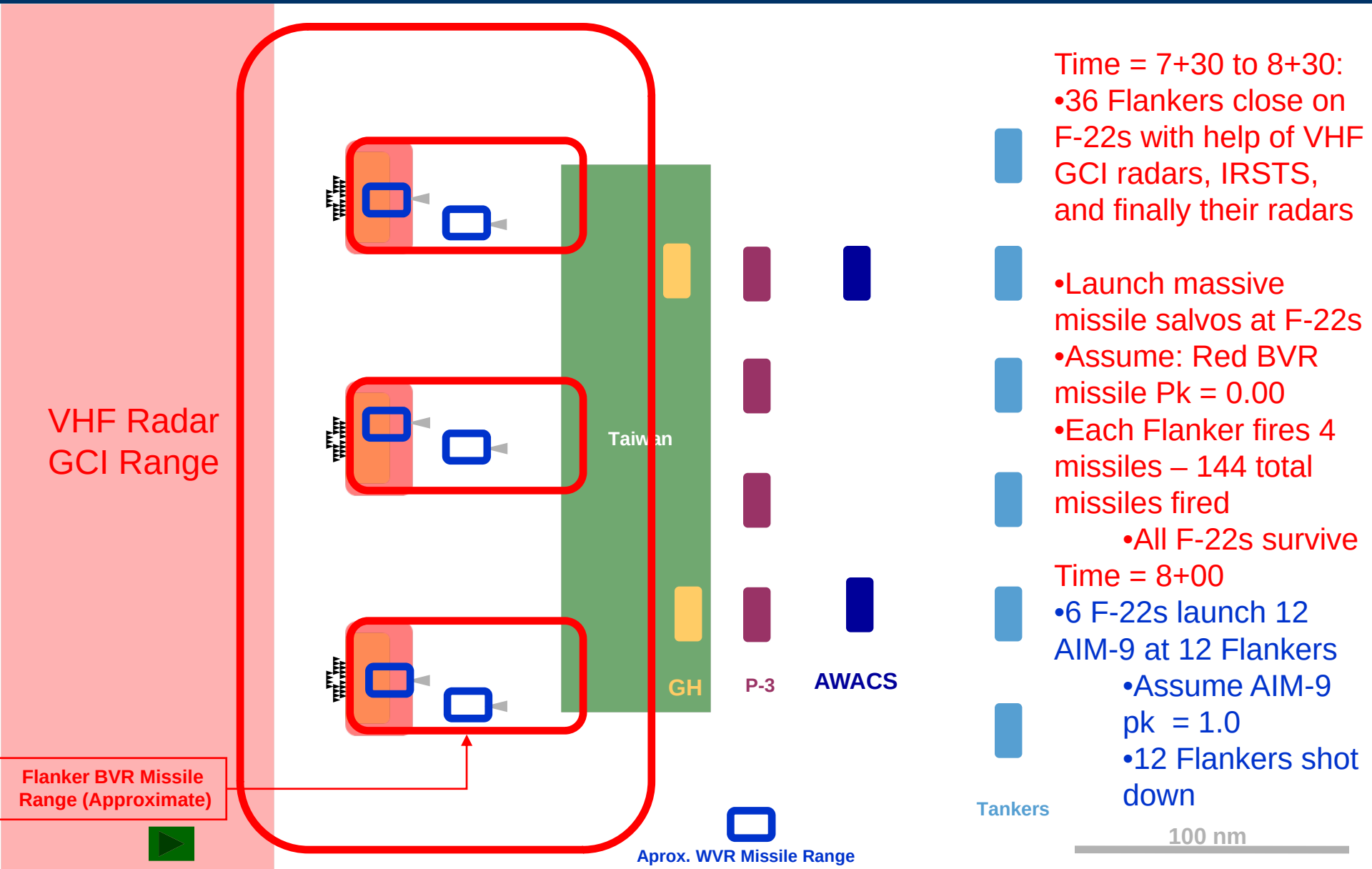


Time 7+15:

- 6 F-22s close 36 surviving Flankers but only have 12 WVR missiles

- Note: F-22s could run, but if they do and the Flankers kill the Tankers where will they land?

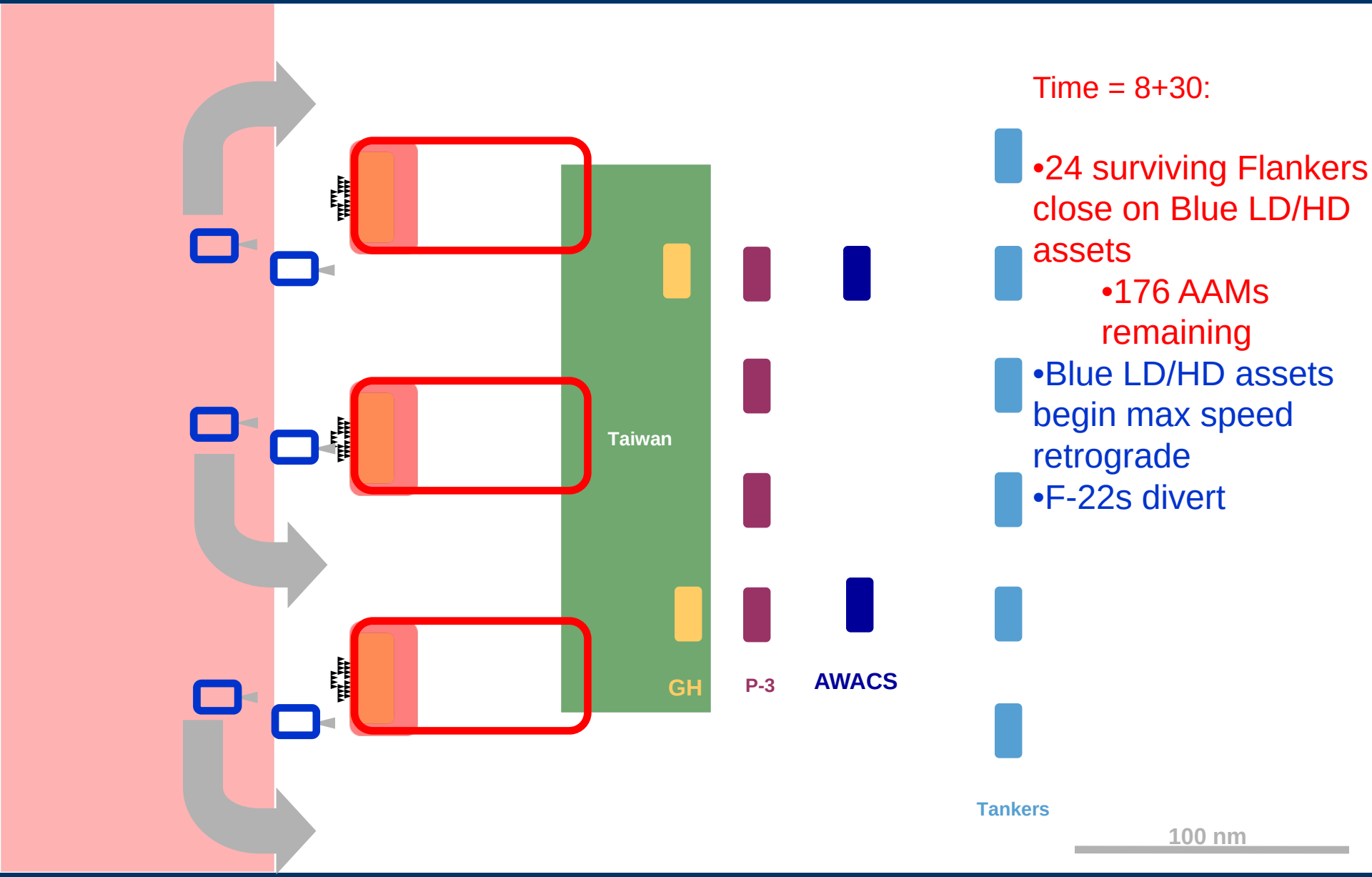
2020 Employment Example



Time = 7+30 to 8+30:
- 36 Flankers close on F-22s with help of VHF GCI radars, IRSTS, and finally their radars
- Launch massive missile salvos at F-22s
- Assume: Red BVR missile Pk = 0.00
- Each Flanker fires 4 missiles – 144 total missiles fired
  - All F-22s survive

Time = 8+00
- 6 F-22s launch 12 AIM-9 at 12 Flankers
  - Assume AIM-9 pk = 1.0
  - 12 Flankers shot down

2020 Employment Example



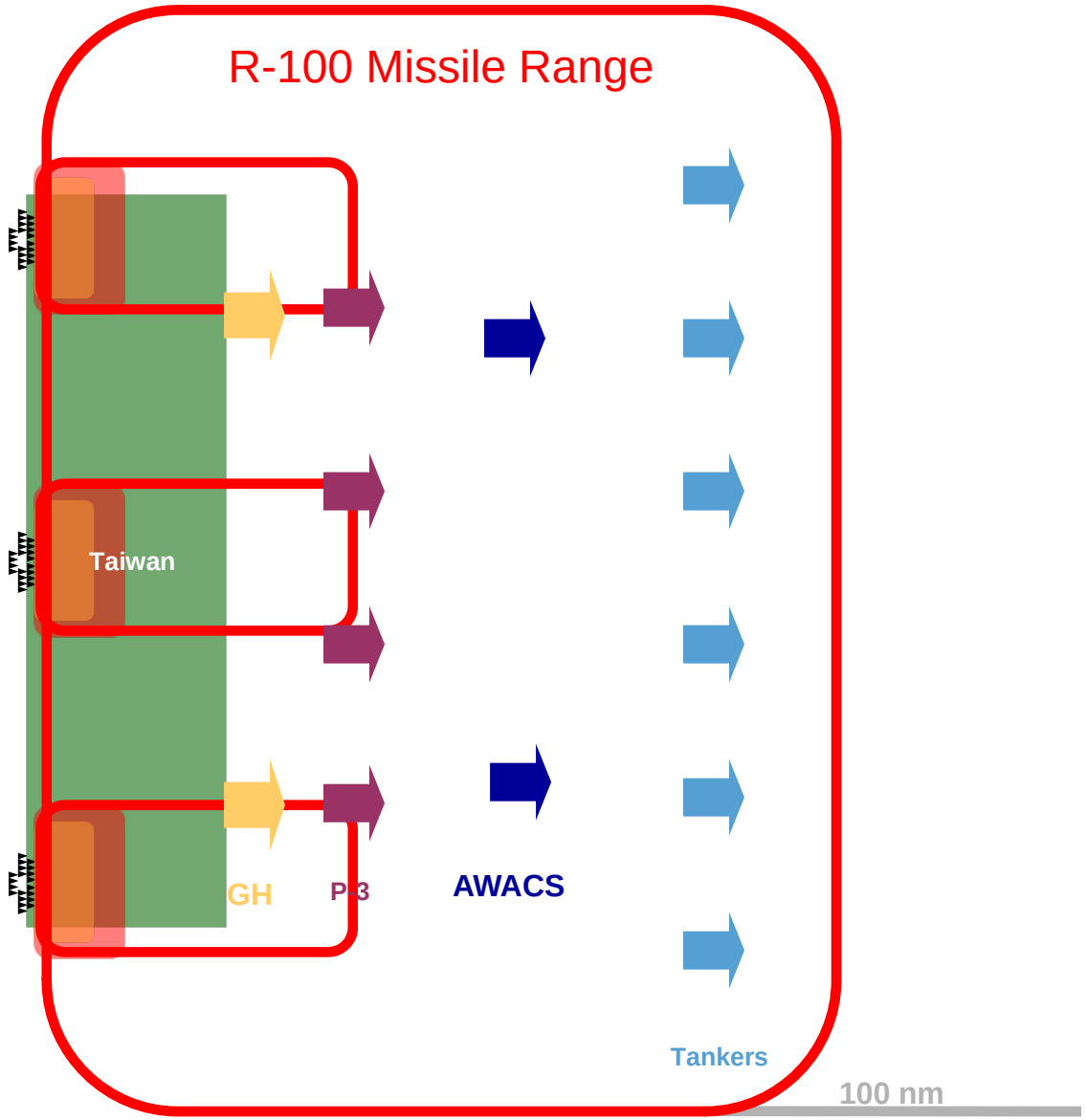
Time = 8+30:

- 24 surviving Flankers close on Blue LD/HD assets
  - 176 AAMs remaining
- Blue LD/HD assets begin max speed retrograde
- F-22s divert

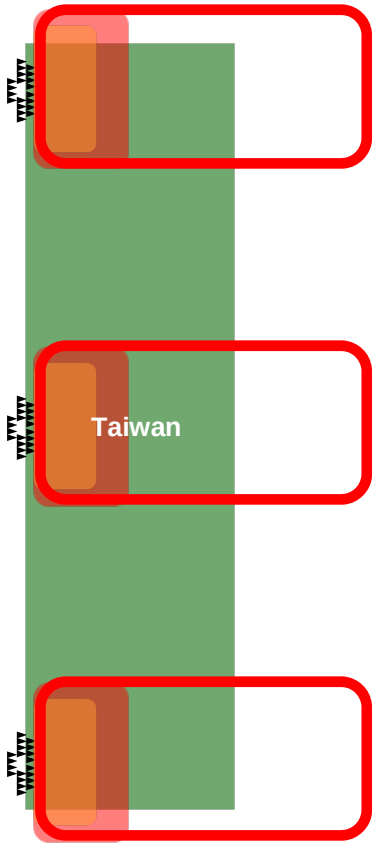
2020 Employment Example

Time = 13+15 to14+15:

- Flankers use 48 very long range AAMs to attack and kill AWACS and Tankers
  - With 0.5 Pk likely US losses
    - 6 tankers
    - 2 AWACS
- Use 24 AA-12 or PL-12 to kill P-3 and Global Hawk



2020 Employment Example



Time = 15+00:
- Overall results:
- Red loses:
  - 48 Flankers
- Blue loses:
  - 0 F-22
  - 6 Tankers
  - 2 AWACS
  - 4 P-3
  - 2 Global Hawk
- Red owns air over Taiwan – at least for now
  - 24 Flankers survive
  - 104 AAMs remaining

100 nm

Assessment

- F-22s shoot down 48 Flankers when outnumbered 12:1 without loss
- BUT,
  - Example assumed perfect Pk for US BVR missiles and 0 Pk for PLAAF missiles vs. F-22
  - Example assumed very simple PLAAF tactics – "Damn the AMRAAMs, full speed ahead!"
  - Example assumed no PLAAF stealthy aircraft –*possible by 2020 to 2025*
  - Example assumed no use of "robo-fighters" to deplete USAF fighters missile loadout prior to mass attack
- Even with perfect missiles and invulnerable fighters protecting LD/HD assets requires force ratio of 8.0 or less
  - More complex tactics, more realistic missile Pk assumptions or better PLAAF equipment could alter this substantially
- If loss of 14 high-value assets included overall USAF exchange ratio is 3.4:1
- Most Flanker losses occurred over China so pilots likely recovered by PLA
  - If 80 percent of pilots survive, then total PLAAF crew loss is 10 pilots
- USAF losses occurred over Philippine Sea
  - LD/HD crews lack ejection seats so unlikely to survive
  - USAF/USN crew losses: Tankers 18, P-3s 40+, E-3s 50+ TOTAL 120+

PAK-FA

J-XX

More reasonable BVR missile Pk assumptions result in 3:1 or lower kill ratio in favor of F-22

- Red CONOP is simple
  - No missile defeat maneuvers
  - Easy navigation and timing coordination
  - "If confused head East high and fast and shoot at Blue airplanes"
- Flanker/F-22 kill ratio is:
  - *Extremely insensitive to Red BVR missile Pk* due to massive salvo tactics
  - *Highly sensitive to Blue BVR missile Pk*

BVR Combat Exchange Ratio

Exchange Ratio R/B								F-22s On Station	F-35s On Station
	Blue BVR Missile Pk							6	0
Red BVR Missile Pk	1.0	0.90	0.75	0.50	0.25	0.10	0.05	0.01	Missiles Fired	Missiles Fired
0.90	6.00	5.50	4.50	3.00	1.50	0.67	0.33	0.17	36	0
0.75	6.00	5.50	4.50	3.00	1.50	0.67	0.33	0.17		
0.50	6.00	5.50	4.50	3.00	1.50	0.67			Fighters	
0.25	6.00	5.50	4.50	3.00	1.50	0.67			6	
0.10	6.00	5.50	4.50	3.00	1.50	0.67			siles Fired	
0.05	7.20	6.60	5.40	3.00	1.50	0.67			36	
0.01	18.00	16.50	13.50	9.00	3.00	1.33				
Total Red Fighters										
72										

Likely Outcomes

		Blue BVR Missile Pk							
	1.0	0.90	0.75	0.50	0.25	0.10	0.05	0.01
Red Fighters Killed	36	33	27	18	9	4	2	1
Red Fighters Survive	36	39	45	54	63	68	70	71
Red Missiles Fired	144	156	180	216	252	272	280	284
Red Missile Pk		Blue Fighters Killed						
0.90	6	6	6	6	6	6	6	6
0.75	6	6	6	6	6	6		
0.50	6	6	6	6	6	6		
0.25	6	6	6	6	6	6		
0.10	6	6	6	6	6	6		
0.05	5	5	5	6	6	6		
0.01	2	2	2	2	3	3		

Likely Outcomes

Assuming efficient operations from Japanese bases and nearby carriers helps – but probably not enough

- **Assume:**
  - 120 F-22 plus 90 F-35 operate *unhindered* from Kadena
  - 72 more F-35 operate *unhindered* from Misawa
  - 2 CSGs operate *unhindered* 400 nm from center strait
    - 50% of sorties used for DCA CAPs
  - F-35s fire AIM-120 before Flankers fire AA-12/PL-12

- **Results:**
  - 26 US fighters on station vs. just 6 from Andersen only case
  - More enemy fighters killed and stopping leakers is possible
  - BUT, most likely results are loss of most USAF fighters and 10 or more Flankers leaking through

BVR Combat Exchange Ratio

Exchange Ratio R/B								F-22s On Station	F-35s On Station
	Blue BVR Missile Pk							10	16
Red BVR Missile Pk	1.0	0.90	0.75	0.50	0.25	0.10	0.05	0.01	Missiles Fired	Missiles Fired
0.90	*Inf*	*Inf*	*Inf*	*2.38*	*1.19*	*0.50*	*0.27*	*0.08*	60	64
0.75	*Inf*	*Inf*	*Inf*	*2.48*	*1.19*	*0.50*	*0.27*	*0.08*		
0.50	*Inf*	*Inf*	*Inf*	*2.95*	*1.19*	*0.50*			nters	
0.25	*Inf*	*Inf*	*Inf*	*4.77*	*1.24*	*0.50*			26	
0.10	*Inf*	*Inf*	*Inf*	*10.33*	*1.82*	*0.65*			s Fired	
0.05	*Inf*	*Inf*	*Inf*	*20.67*	*3.10*	*0.93*			124	
0.01	*Inf*	*Inf*	*Inf*	*62.00*	*10.33*	*3.25*				
Total Red Fighters										
72										

Likely Outcomes

		Blue BVR Missile Pk						
	1.0	0.90	0.75	0.50	0.25	0.10	0.05	0.01
Red Fighters Killed	*72*	*72*	*72*	*62*	*31*	*13*	*7*	*2*
Red Fighters Survive	*0*	*0*	*0*	*10*	*41*	*59*	*65*	*70*
Red Missiles Fired	*0*	*0*	*0*	*60*	*246*	*354*	*390*	*420*
Red Missile Pk	Blue Fighters Killed							
0.90	*0*	*0*	*0*	*26*	*26*	*26*	*26*	*26*
0.75	*0*	*0*	*0*	*25*	*26*	*26*		
0.50	*0*	*0*	*0*	*21*	*26*	*26*		
0.25	*0*	*0*	*0*	*13*	*25*	*26*		
0.10	*0*	*0*	*0*	*6*	*17*	*20*		
0.05	*0*	*0*	*0*	*3*	*10*	*14*		
0.01	*0*	*0*	*0*	*1*	*3*	*4*		

Likely Outcomes

Conclusions

- To fight and win outnumbered with current and planned systems USAF will need:
  - Secure, close bases
  - BVR to work
  - Stealth to work

- History and prudence suggest some or all of these ***necessities*** may not be robust or reliable in a future conflict with the PLA and perhaps others

Implications for USAF basing and operations

- Numbers and firepower matter and could be used to counter USAF qualitative advantages
- WESTPAC bases face unprecedented scale and quality of threat
- "Classic Air Superiority" is an enabler of all other ops
  - do we have it if we can't stop missiles?
- AIM-120 missile Pk and numbers are critical
  - Possible short to medium term improvements:
    - Seeker diversity key improvement
    - Increasing on-station missile supply
- Counter stealth, anti-access, counter BVR technologies are proliferating
  - Need a plan that accounts for this - - over time not just a WESTPAC problem

Need "plan B" to achieve U.S. campaign objectives absent "classic" air superiority

PROJECT AIR FORCE

Backup

Lebanon 1982

- Israeli Air Force vs. Syrian Air Force June 9-11, 1982
  - Both sides commit about 150 aircraft
  - IAF claim 85 Syrian aircraft in air-to-air combat while losing zero
  - IAF admits losing 19 aircraft to Syrian SAMs in Bekka Valley (about 13 percent)
  - Syrian AF admits losing 85 aircraft (about 56 percent)
    - Recent scholarship reveals SAF claims 4 MiG-23M BVR kills vs. F-16s
    - In each case missile launch and impact ranges are reported and SAF admits launching aircraft shot down by victim's wingman with WVR missile
      - Source: http://en.wikipedia.org/wiki/Mikoyan-Gurevich_MiG-23

- Is it possible that 4 of 19 IAF losses were to BVR air-to-air missile shots rather than SAMs?
  - If so, then kill ratio as "low" as 21:1

- Force comparison
  - Israelis flying F-15s and F-16s (mostly)
  - Most SAF aircraft MiG-21 and MiG-23 ground attack aircraft
  - Relatively few MiG-23M air-to-air fighters
    - Even these lacked wartime radar and ECM modes
  - Superior IAF training, ISR support (E-2)
  - IAF had initiative

"The bomber will always get through" (1 of 3)

- 1930s air planners assumed:
  - Primary mission of air forces to drive home bomber attack
  - Bombers to "destroy enemy means of making war"
  - Follows bombers must strike deep
  - No escort fighter can compete with short range interceptors
  - Bombers would be faster, higher flying and more heavily armed than fighters
  - "A well equipped, well trained bomber formation can defend itself from fighter attack"
  - Failure of European bombers to do this dismissed by USAAF in 1940 as the result of:
    - Insufficient armament
    - Poor training
    - Poor tactics

http://www.woodburnevansheadrsl.com.au/history/fairy_battle.jpg

- 1940-1943 USAAF air planners assumed:
  - USAAF bombers so fast head on attacks impossible
    - Most attacks would come from 20 deg cone in rear
  - Tail armament most important and must equal fighter firepower
  - Manually aimed and turreted guns more accurate than fixed fighter armament

http://home.st.net.au/~dunn/ozcrashes/bak04.jpg

"The bomber will always get through" (2 of 3)

- Virtually all of these assumptions proved mistaken
  - Fighter speed and firepower improved rapidly once the need arose
    - By 1943 bombers *slower, lower flying and less heavily armed* than fighters
  - European experience *was* relevant to USAAF bombers
  - Frontal attacks *were* possible
  - Flexible guns were 10 times *less* effective than fixed fighter armament
  - Escort fighters *could* compete with interceptors
- Result – daylight precision bombing too costly until escort fighters deployed in early 1944 – then air superiority rapidly achieved over Germany

It is easy for even large groups of smart people to get important assumptions wrong

"The bomber will always get through" (3 of 3)

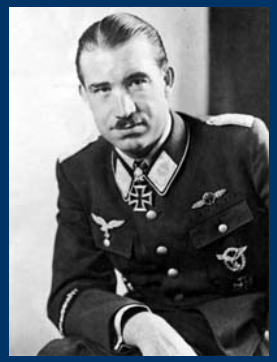
- First Schweinfurt Aug 17, 1943:
  - 8th AF loses 149 of 363 dispatched (41 %):
    - 60 Bombers destroyed
    - 47 Damaged beyond repair
    - Additional 42 abandoned in North Africa as not repairable within a week
- Munster Oct 10, 1943:
  - 30 bombers destroyed of 274 dispatched
    - Including 12 of 13 100th Bomb Group aircraft (92 % losses)
- Second Schweinfurt Oct 14, 1943:
  - 8th AF losses 198 of 291 dispatched (68%)
    - 65 destroyed – including 13 of 16 from 305th bomb group (81 % losses)
    - 12 damaged beyond repair
    - 121 heavily damaged
    - Only 62 aircraft returned from mission lightly- or un- damaged

It is easy for even large groups of smart people to get important assumptions wrong

How Much Can Quality Compensate for Quantity? (Backup)

- Exchange Ratio (E) = kills/losses
- Force Ratio (F) = Adversary Sorties/Friendly Sorties
- Quality (Q) = E* F
  - Example: 10 fighters meet 20 adversary fighters, each side kills 5 opposing aircraft
    - E = 5/5 = 1.0
    - F = 20/10 = 2.0
    - Q = 1.0 * 2.0 = 2.0
- 2 biggest days for JV 44:
  - 18 March and 10 April 1945
  - Overall
    - 92 sorties
    - 22 kills
    - 29 losses
  - Pk per jet fighter sortie ~ 0.24
  - Pk per sortie for Luftwaffe piston engine fighters 1944 ~ 0.01
  - Faced over 1100 USAAF escort fighter sorties
    - Pk per sortie vs. jets = 0.026
    - Pk per sortie vs. piston engine fighters 1944 = 0.024
  - Exchange ratio, E: 22/29 = 0.76
  - Force ratio, F: 1100/92 = 11.95
  - Q = E*F = 0.76*11.95 = 9.1
- If Lanchester square equation applies maximum break-even force ratio for JV-44 was 9.1^0.5 = 3.01


http://www.kheichhorn.de/assets/images/me262_3.jpg


Adolf Galland
(104 kills)


Johannes Steinhoff
(176 kills)


Heinrich Bar
(221 kills)


Gerhard Barkhorn
(301 kills)


Walter Krupinski
(197 kills)

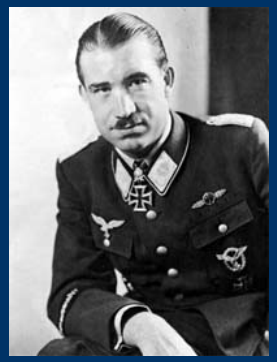

Günther Lützow
(110 kills)

How Much Can Quality Compensate for Quantity? (Backup)

- **Assessment of Me-262:**
- ***"If asked to nominate the most formidable combat aircraft to evolve in World War II, I would unhesitatingly propose Messerschmitt's Me 262. I say 'unhesitatingly' despite having flown the Spitfire in virtually all of its variants, the Mosquito, the Lancaster, the Mustang and even the Mitsubishi Zero-Sen; all warplanes that might be considered for this accolade."***
- ***"That, then, was the Me 262, variously known as the Schwalbe and the Sturmvogel. But by whatever the appellation, it was in my view unquestionably the foremost warplane of its day; a hard hitter which outperformed anything that we had immediately available but which, fortunately for the Allies, was not available to the Luftwaffe in sufficient numbers to affect drastically the course of events in the air over Europe. It was a pilots aeroplane which had to be flown and not just heaved into the air. "***

Captain Eric "Winkle" Brown (RN) chief test pilot at the Royal Aircraft Establishment in Farnborough. Brown flew a world record 487 different types of aircraft including virtually all US, UK, German, Italian and Japanese combat aircraft of WWII

http://www.kheichhorn.de/assets/images/me262_3.jpg



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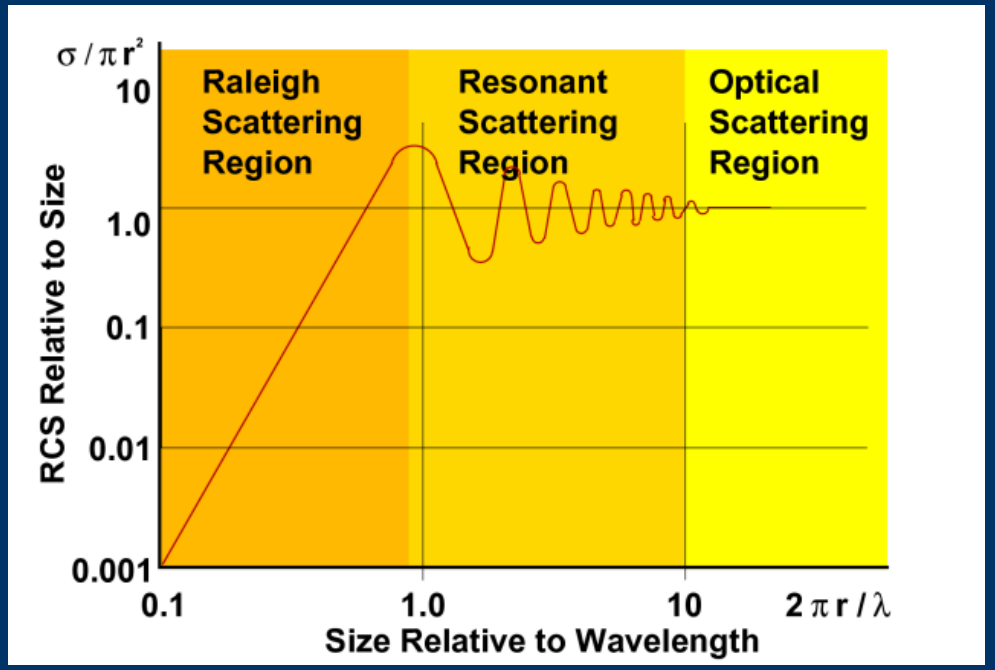
Stealth, Aircraft Size and Radar Frequency

- Physics of radar scattering depend on the size of the radar wavelength vs. the physical size of the target
- Raleigh scattering regime wavelength is similar or greater in magnitude to the physical size of the target
  - Magnitude of reflection is proportional to the physical size of the target
- In resonant scattering wavelength is comparable in size to key shaping features on the target
  - The magnitude of the reflection fluctuates strongly with wavelength and aspect
- In optical scattering target shaping can be used to precisely control the magnitude and direction of reflections
  - High effectiveness of stealth designs against decimetric and centimetric band radars reflects the reality that for most aircraft sizes, these wavelengths are a tenth to a hundredth of the size of key shaping features



Courtesy Air Power Australia @ http://www.ausairpower.net/

Legacy Platforms

RAND

Adapted from: CAF 2025 Flight Plan

Stealth, High Altitude, & Speed

RAND

Adapted from: CAF 2025 Flight Plan

All Fighter-Size Platforms

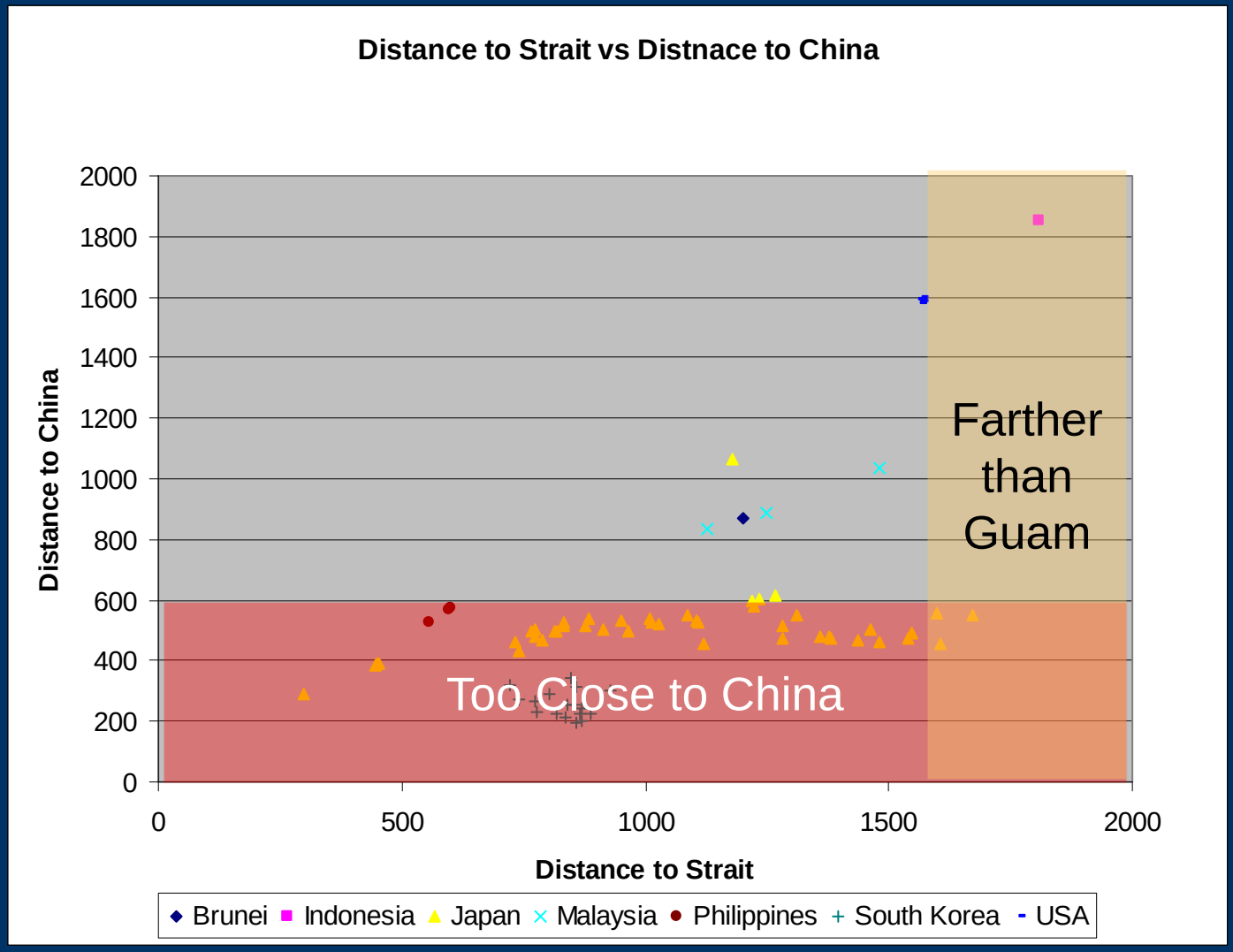
RAND

Airbases are Interdependent Systems

- **Sortie generation requires:**
  - **Aircraft**
  - **Operating surfaces**
  - **Fuel**
  - **Maintenance vehicles and equipment**
  - **Command and control facilities**
  - **People to run and maintain all this stuff**
  - **And much more**

- **Cold War hardening program began with aircraft and spread to other airbase systems because**
  - **Aircraft are the most expensive component**
  - **Aircraft are easily damaged 'soft' targets**
    - **Repair and recovery difficult or impossible**
  - **Aircraft are absolutely necessary (but not sufficient) for sortie generation**

Very Few Airfields in the Western Pacific



Lanchester Equation Basics

- F.W. Lanchester was among the first theorists to apply higher mathematics to warfare. In 1916, he began to analyze the aerial war that was taking place over Europe.
- The applicability of the Square Law is limited to aimed fire situations. These include any combat where the units involved are firing at enemy units, and correcting their fire to avoid 'killed' targets. Rifle duels, tank combat, air to air combat, all of these apply.

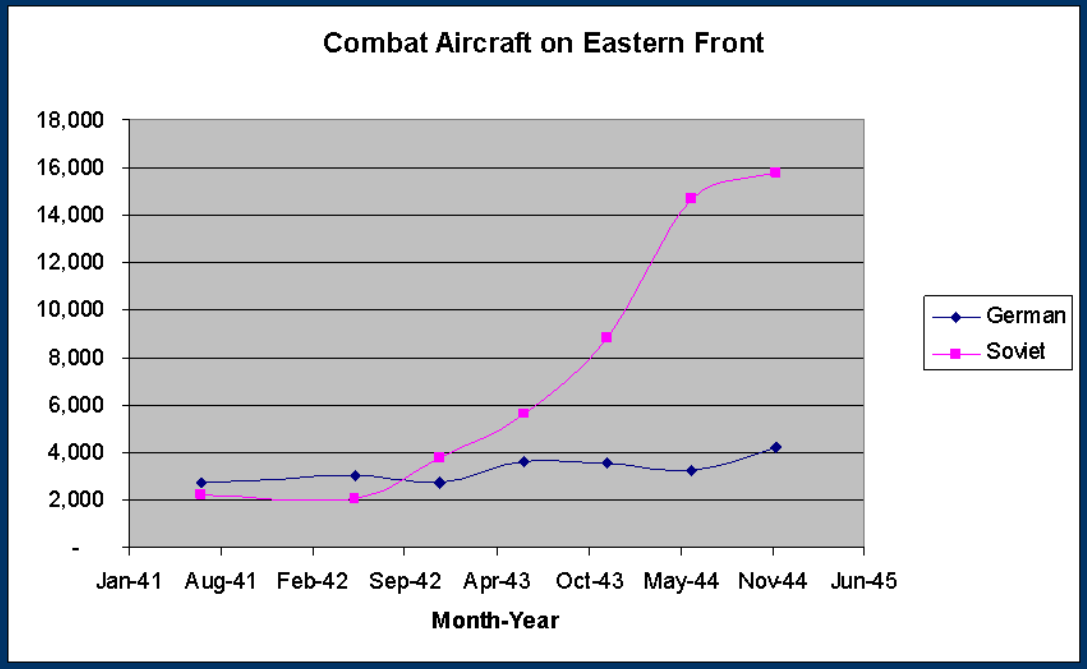
(3) *Numbers (quantities) get squared, but effectiveness (quality) does not*. In the Lanchester square stalemate expression the number of forces is squared, while firing effectiveness is not; hence, to stalemate a force thrice as numerous, one must be nine—or N^2—times as effective.[14] This dramatic bias in favor of numbers follows mathematically from the baseless implicit assumption that fire can be concentrated perfectly, or equivalently, that there are never any diminishing marginal returns to numbers. For instance, no force-to-space constraints ever set in. But, of course, they—and all manner of other constraints—do set in.[15]

Joshua M. Epstein, *Dynamic Analysis and the Conventional Balance in Europe*, International Security, Vol. 12, No. 4, (Spring, 1988), pp. 154-165

- This critique applies less to modern BVR air-to-air combat than virtually any previous form of combat
  - Long range weapons, networking, advanced sensors allow efficient detection and targeting of adversary aircraft
  - Effective range of weapons and sensors allows air battles across enormous volumes of sky – unlikely to face force-to-space constraints

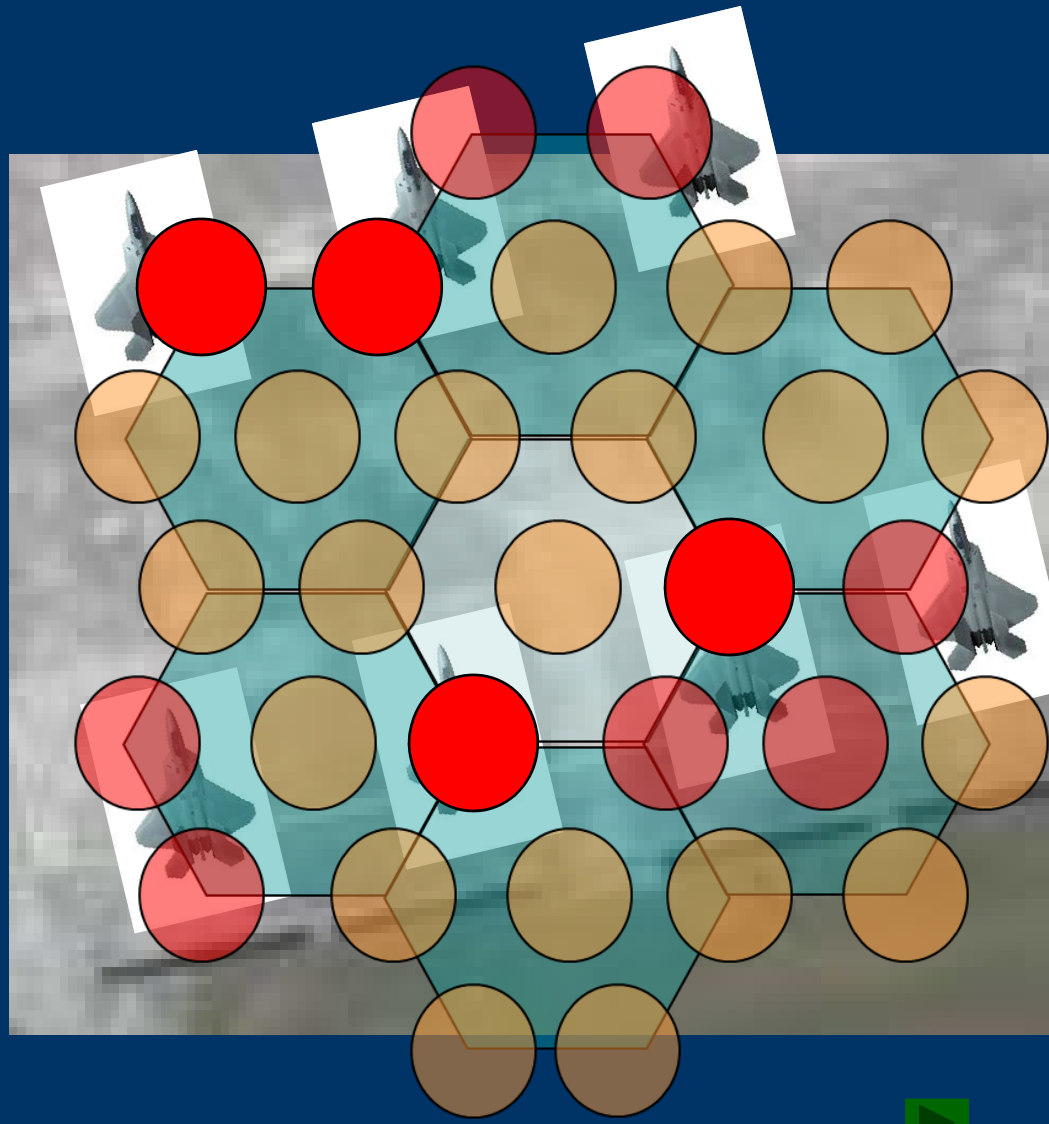
Eastern Front Force Ratios

- Luftwaffe and Red Air Force numbers fairly close through mid-1943
- Luftwaffe unable to establish firm air superiority during Battle of Kursk July 1943
- Soviet numbers increasingly determined air superiority struggle for rest of war



Missile Attack Example: Submunition Warheads

- SRBM-class warhead characteristics:
  - Assume 75 percent of warhead weight devoted to submunitions
    - Consistent with existing systems
  - So, 1,100 lb (500 kg) warhead yields 825 one pound submunitions
  - Submunition effective radius against aircraft ~20 feet
  - 52 foot spacing ensures multiple hits
- Total warhead effective radius ~ 710 ft (215 m)



Note: Only 31 of 825 submunitions shown

Aircraft at Kadena and Andersen

- Kadena: Analogous to Aviano AB Italy in 1999 and Shaikh Isa in 1991
  - Aircraft types are different
  - Aircraft missions and numbers similar

Aircraft	Number	Airborne	Taxi	Parked
F-22	72	15	1	56
F-15E	24	5	0	19
F-35	96	21	2	73
EC-130	4	0	0	4
EF-18G	32	7	0	25
E-3	3	0	0	3
KC-135	12	2	0	10
Total	243	50	3	190

- Andersen: Analogous to Mildenhall and Fairford 1991 and 1999
  - Aircraft types are different
  - Aircraft missions and numbers similar

Aircraft	Number	Airborne	Taxi	Parked
B-1	15	4	0	11
B-2	4	1	0	3
B-52	20	6	0	14
KC-135	98	29	2	67
KC-45	32	9	0	23
E-3	3	0	0	3
C-130	8	2	0	6
C-17	6	1	0	5
Q-4	4	1	0	3
F-22	48	14	1	33
Total	238	67	3	168

Aircraft on Parking Ramp Assumptions

- Assumed prior to conflict all crews fly at maximum peacetime rate of 125 hours per 30 days
- Assumed crew ratios
  - Fighters: 1.25
  - Heavies: 1.75
- Aircraft airborne each day:
  - Fighters 1.25 * 4.15 = 5.19 hours on average (22 percent)
  - Heavies 1.75 * 4.15 = 7.26 hours on average (30 percent)
- Aircraft spend 30 minutes per day on taxiways (2 percent)
- Percent of aircraft parked on average:
  - Fighters - - about 76 percent
  - Heavies - - about 68 percent

Aircraft Damage Assumptions

- Airborne aircraft survive
- Taxiing aircraft are assumed to take off prior to attack and are not damaged
- Aircraft parked in open or flow-thru structures subject to submunition attack
- Submunition attacks cover 90 percent of parking and flow-thru area
  - 10 percent of parked aircraft suffer little or no damage but are stuck due to UXOs, FOD and lack of AGE
  - ¾ of remaining parked aircraft destroyed by submunitions or ensuing fires
  - ¼ of remaining parked aircraft severely damaged
  - ¾ of AGE also destroyed
- 15 F-22s, 4 B-2s, 4 Q-4s routinely parked in shelters
  - Shelters attacked by cruise missiles after ballistic missile attack but before airfield is cleared of debris

Attack Results at Kadena and Andersen

Kadena Attack Results

Aircraft	Number	Airborne	Taxi	Parked	Hit Submunitions	Destroyed	Damaged (severe)	Stuck	Hit by CM in Shelters	Destroyed in Shelters
F-22	72	15	1	56	39	29	10	5	12	12
F-15E	24	5	0	19	17	12	5	2	0	0
F-35	96	21	2	73	65	48	17	8	0	0
EC-130	4	0	0	4	3	2	1	1	0	0
EF-18G	32	7	0	25	22	16	6	3	0	0
E-3	3	0	0	3	2	1	1	1	0	0
KC-135	12	2	0	10	9	6	3	1	0	0
Total	243	50	3	190	157	114	43	21	12	12

Andersen Attack Results

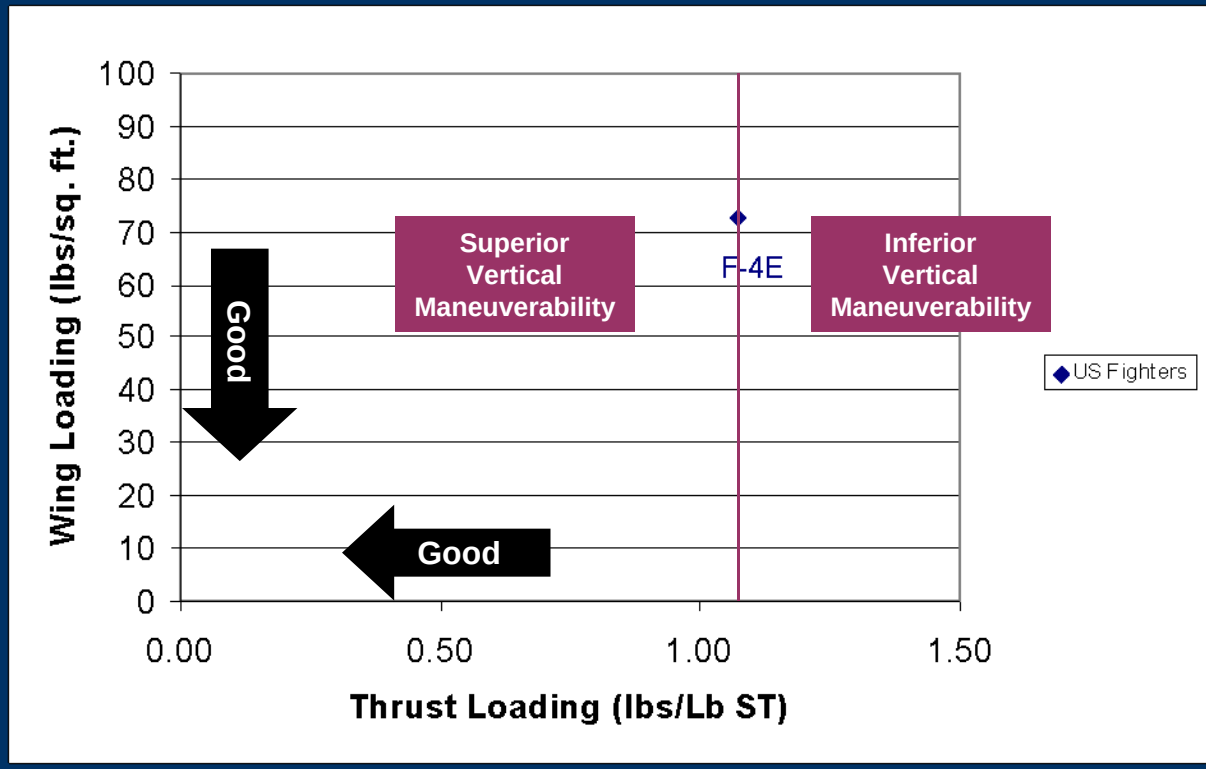
Aircraft	Number	Airborne	Taxi	Parked	Hit Submunitions	Destroyed	Damaged (severe)	Stuck	Hit by CM in Shelters	Destroyed in Shelters
B-1	15	4	0	11	9	6	3	2	0	0
B-2	4	1	0	3	0	0	0	0	3	3
B-52	20	6	0	14	12	9	3	2	0	0
KC-135	98	29	2	67	60	45	15	7	0	0
KC-45	32	9	0	23	20	15	5	3	0	0
E-3	3	0	0	3	2	1	1	1	0	0
C-130	8	2	0	6	5	3	2	1	0	0
C-17	6	1	0	5	4	3	1	1	0	0
Q-4	4	1	0	3	0	0	0	0	3	3
F-22	48	10	1	37	0	0	0	0	37	37
Total	238	63	3	172	112	82	30	17	43	43

Overall Attack Results

Aircraft	Number	Recovered Elsewhere	Destroyed	Damaged (severe)	Stuck
Grand Total	481	119	251	73	38
Percent	100%	25%	52%	15%	8%

Relative Visual Range Combat Capability

- Our current "Plan B" is to close to visual range and engage enemy aircraft
  - In this case relative aircraft turn and acceleration performance matters a great deal
- Depending on relative performance four tactical relationships are possible
  - Enemy has superior vertical maneuverability
  - Enemy has superior horizontal maneuverability
  - Enemy superior in both
  - Enemy inferior in both



Note: All calculations based on data from Jane's and assume:
- 50 percent internal fuel
- Full air-to-air missile load

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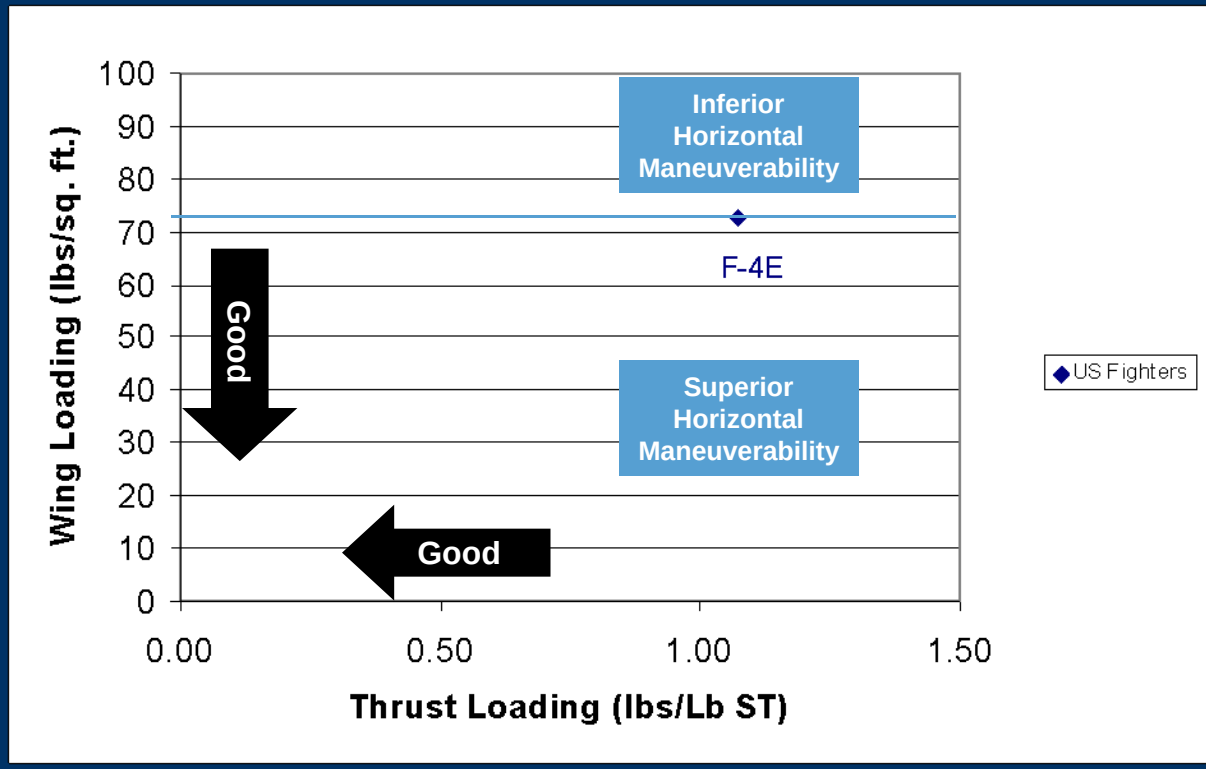

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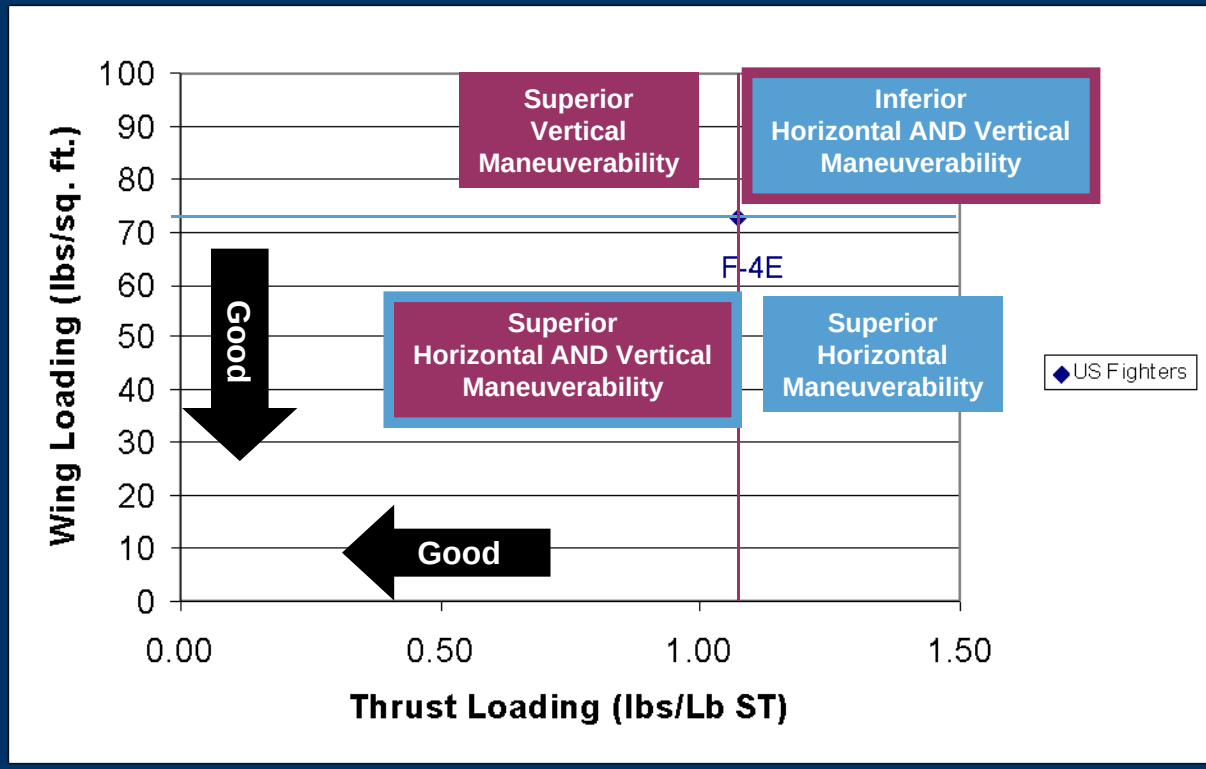

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Relative Visual Range Combat Capability: Best Adversary Tactics

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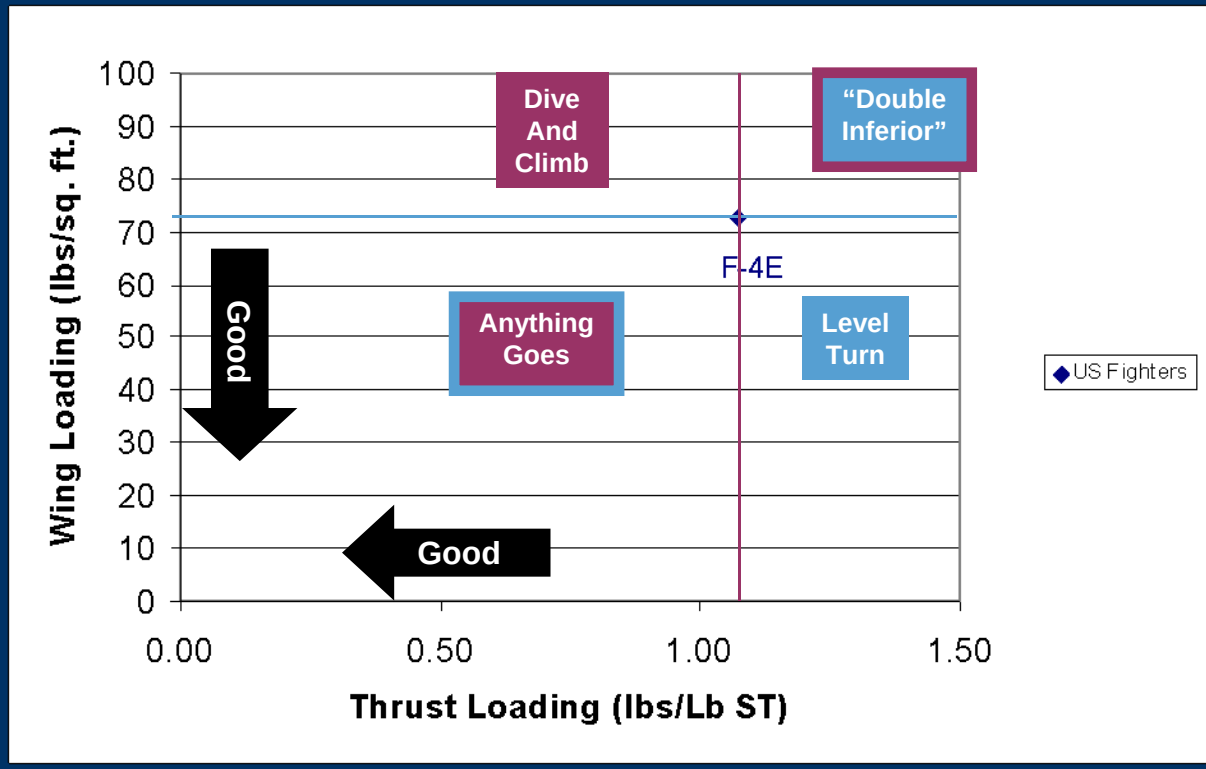
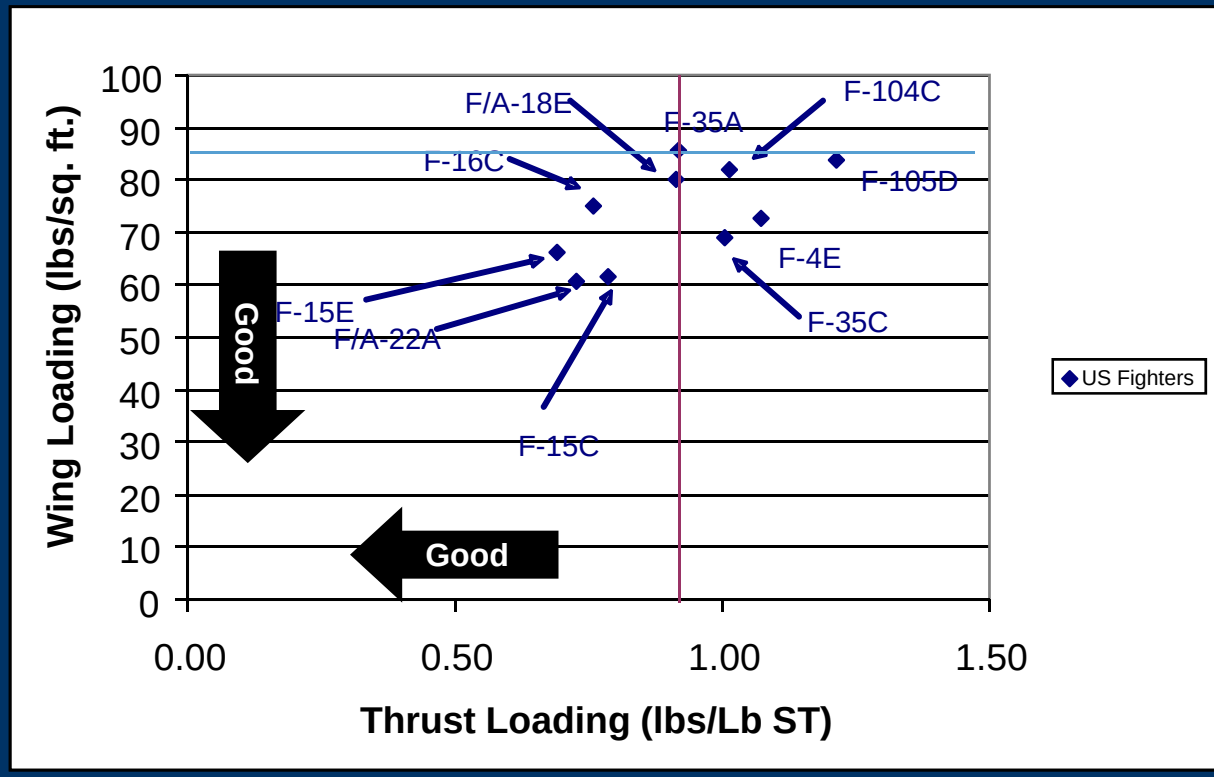


Note: All calculations based on data from Jane's and assume:
- 50 percent internal fuel
- Full air-to-air missile load

Relative Visual Range Combat Capability

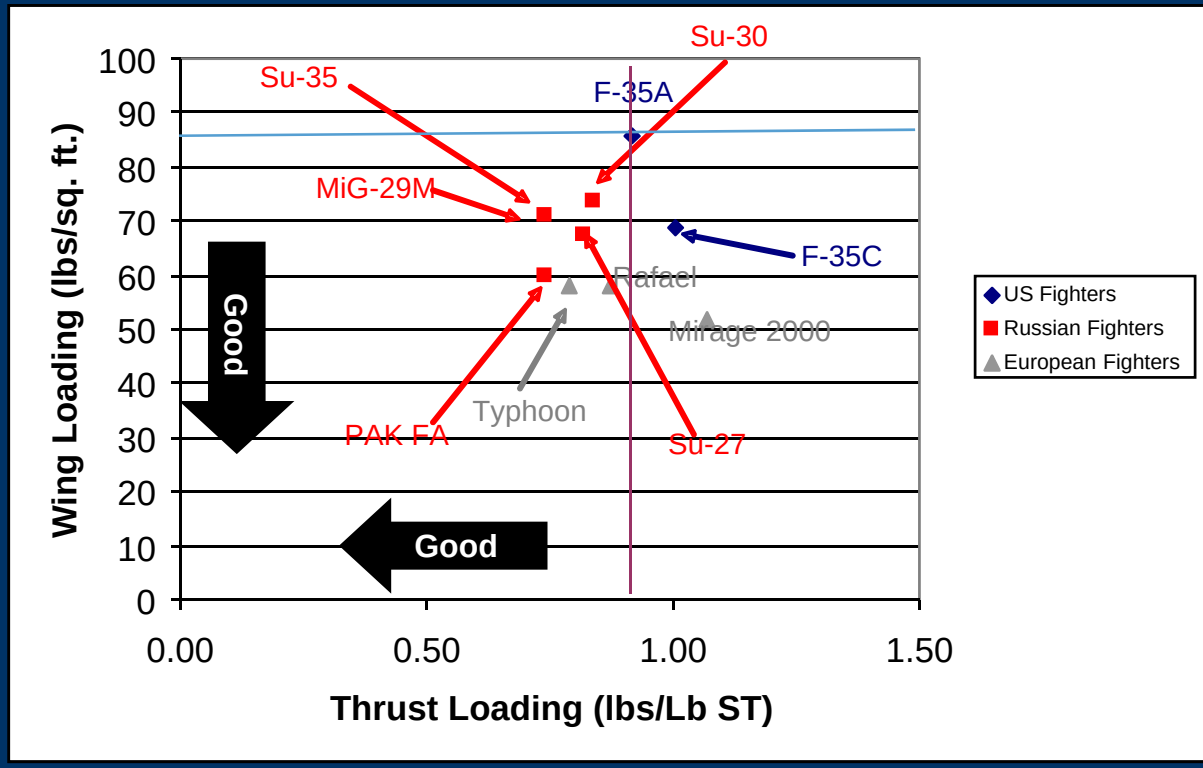
- F-35 optimized for strike – not air-to-air maneuvering combat
- Thrust loading is significantly inferior to F-15, F-16 and F-22
  - Slower acceleration, slower climb, more energy bleed in tight turns
- Wing loading is high – comparable to F-105
  - Less agile and requires higher thrust to maintain a given turn radius and speed



Note: All calculations based on data from Jane's and assume:
- 50 percent internal fuel
- Full air-to-air missile load

Relative Visual Range Combat Capability

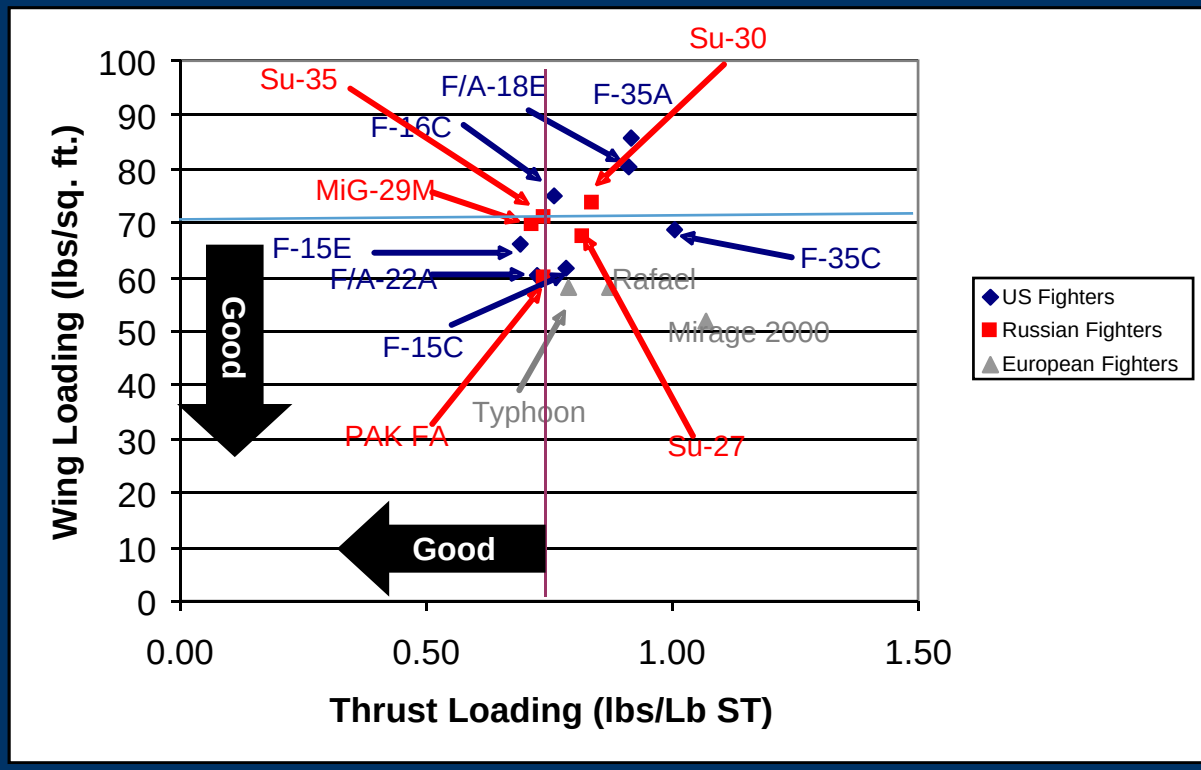
- **F-35A is "Double Inferior" relative to modern Russian/Chinese fighter designs in visual range combat**
  - **Inferior acceleration, inferior climb, inferior sustained turn capability**
  - **Also has lower top speed**
  - **Can't turn, can't climb, can't run**



Note: All calculations based on data from Jane's and assume:
- **50 percent internal fuel**
- **Full air-to-air missile load**

Relative Visual Range Combat Capability

- Only US fighters potentially superior to advanced Flanker variants like SU-35UB are:
- F-15E and F-22A
  - But SU-35 has vectored thrust engines like F-22
  - F-15E does not



Note: All calculations based on data from Jane's and assume:
- 50 percent internal fuel
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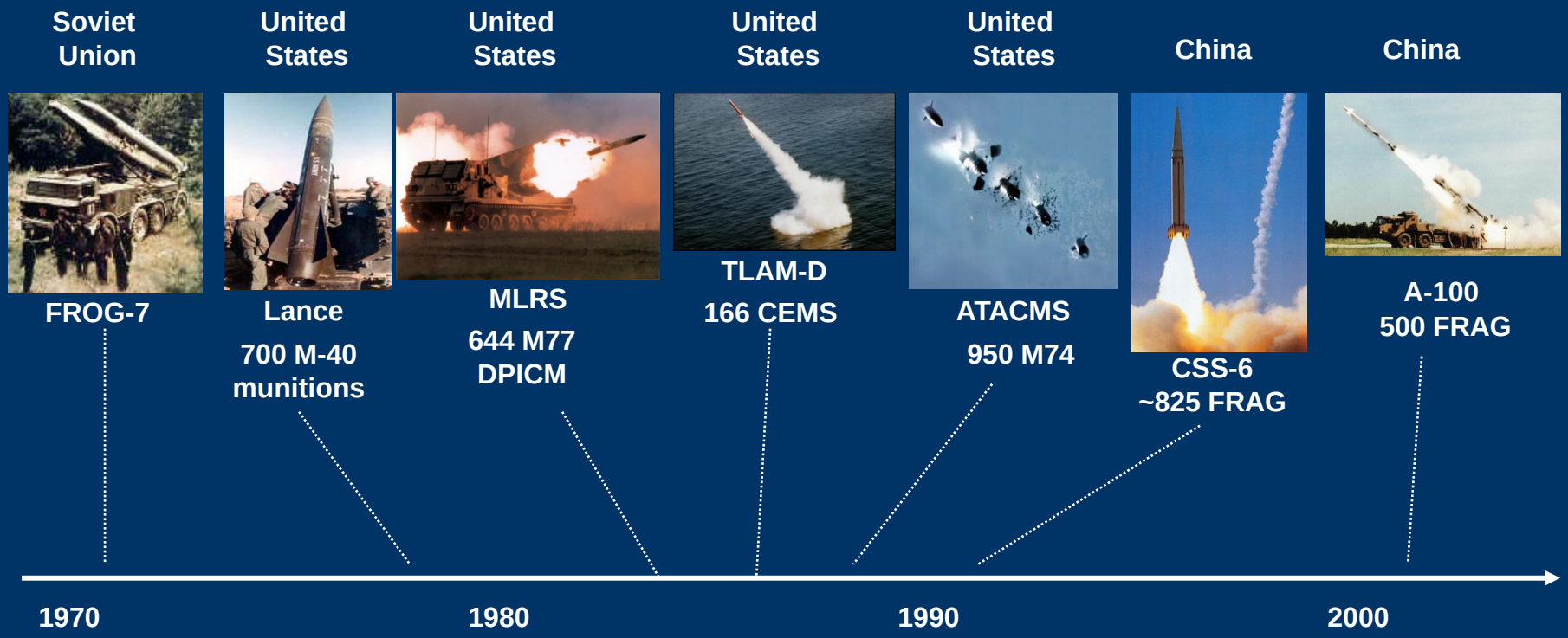
Missile systems that deliver sub-munitions are not new



*Sinodefence.com reports submunition capability. We estimate up to 825 submunitions.

But How Applicable Is This Track Record?

Date	Unit	Aircraft	Pilot	Weapon	Victim	Country	Fired
27-Dec-92	USAF	F-16D		AIM-120A	MiG-25PD	IrAF	1
17-Jan-93	USAF	F-16C		AIM-120A	MiG-29B	IrAF	1
28-Feb-94	86FS/526FW	F-16C 89-2137	B.Wright	AIM-120A	J-21	RVRS (Pesic KIA)	1
14-Apr-94	53FS/52FW	F-15C	E.Wickson	AIM-120A	UH-60A	US Army	1
24-Mar-99	322 sqn KLu	F-16A/MLU J-063	P.Tankink	AIM-120A	MiG-29 18106	127.lpe/JRViPVO (Milutinovic OK)	1
24-Mar-99	493EFS/48FW	F-15C 86-0169	C.Rodriguez	AIM-120C	MiG-29 18112	127.lpe/JRViPVO (Arizanov OK)	1
24-Mar-99	493EFS/48FW	F-15C 86-0159	M.Shower	AIM-120C	MiG-29 18111	127.lpe/JRViPVO (Nikolic OK)	3
26-Mar-99	493EFS/48FW	F-15C 86-156	J.Hwang	AIM-120C	MiG-29 18113	127.lpe/JRViPVO (Radosavljevic KIA)	1
26-Mar-99	493EFS/48FW	F-15C 86-156	J.Hwang	AIM-120C	MiG-29 18114	127.lpe/JRViPVO (Peric OK)	2
4-May-99	78EFS/20FW	F-16C 91-0353	M.Geczy	AIM-120C	MiG-29 18109	127.lpe/JRViPVO (Pavlovic KIA)	1

- **U.S. has recorded ten AIM-120 kills**
  - **Four *not* Beyond Visual Range**
  - **Fired 13 missiles to achieve 6 BVR kills Pk = 0.46***
  - **Iraqi MiGs were fleeing and non-maneuvering**
  - **Serb J-21 had no radar or Electronic Countermeasures (ECM)**
  - **US Army UH-60 not expecting attack; no radar or ECM**
  - **Serb MiG-29 FULCRUMS had inoperative radars**
  - **No reports of ECM use by any victim**
  - **No victim had comparable BVR weapon**
  - **Fights involved numerical parity or US numerical superiority**
- **None of these likely to apply to fight with Chinese FLANKERS**

MiG-29 Fulcrum Fighter

***Note: In addition to kills listed above, on 24 March 1999 an F-16AM of the Dutch Air Force damaged a Serb MiG-29 with a single AIM-120A. Also on 24 March another Serb MiG-29 was engaged by 2 or more US fighters and successfully evaded 3 AIM-120Cs.**

How much degradation of BVR performance can our air-to-air concept tolerate?

F-86E and MiG-15 Closely Matched but With Key Differences

- Closely matched on many dimensions
- F-86 had superior turn performance and better gunsight
- MiG-15 had better acceleration, higher ceiling and much heavier armament

Characteristic	F-86E	MiG-15bis
Length	37.5	33.2
Height (ft)	14.75	12.2
Wingspan (ft)	37.1	33.1
Wing Area (sq. ft)	288	222
Empty Weight (lbs)	10,845	7,900
Max Takeoff Weight (lbs)	17,806	13,460
Power (lbs)	5,200	5,950
Max Speed (mph)	679	668
Cruise Speed (mph)	520	520
Rate of Climb (ft/min)	7,250	9,840
Ceiling (ft)	47,200	50,850
Firepower	552	1,373

Air Combat PPF 84

RAND

Recent Scholarship Reveals MiG-15 / F-86 Exchange Ratio Much Closer Than Traditionally Thought

- For decades Western sources reported that USAF F-86s achieved kill ratios as high as 14:1 against the MiG-15
  - Lop-sided kill ratio claimed to be the result of superior USAF pilot training, experience and tactics
  - Research conducted since fall of the Soviet Union casts doubt on these claims
    - Indicates actual number of MiG-15s shot down was just over 200 vs. almost 800 claimed by USAF
    - Overall kill ratio likely closer to 1.8:1 with F-86 kill ratio against Russian flown MiG-15s likely 1.3:1

- Why the big difference between USAF claims and actual MiG kills?

F-86 Armament a Key Factor

- F-86 designed as an air superiority fighter
  - Primary mission to fight other fighters
  - Designers believed six M-3s .50 in machine guns would be sufficient armament
    - Developed versions of M-2 .50 in machine guns of WWII with increased rate of fire
    - Fired 43 gram (1.5 ounce) projectiles with ~ 1 gram of incendiary composition in nose
      - Effectiveness reduced above 35,000 ft (where most Korean War engagements took place)
- MiG-15 designed as a bomber interceptor
  - Carried heavy cannon armament
    - NR-23 23mm cannon fired projectiles weighing 175 grams (6.2 ounces) with 19 grams of HE
      - NR-23 hit ~ 6 times as destructive as .50 in hit
    - N-37 projectiles weighed 729 grams (25.6 ounces) with 49 grams of HE
      - N-37 hit ~ 18 times as destructive as .50 in hit

http://www.quarry.nildram.co.uk/

… and So Was MiG-15 Design

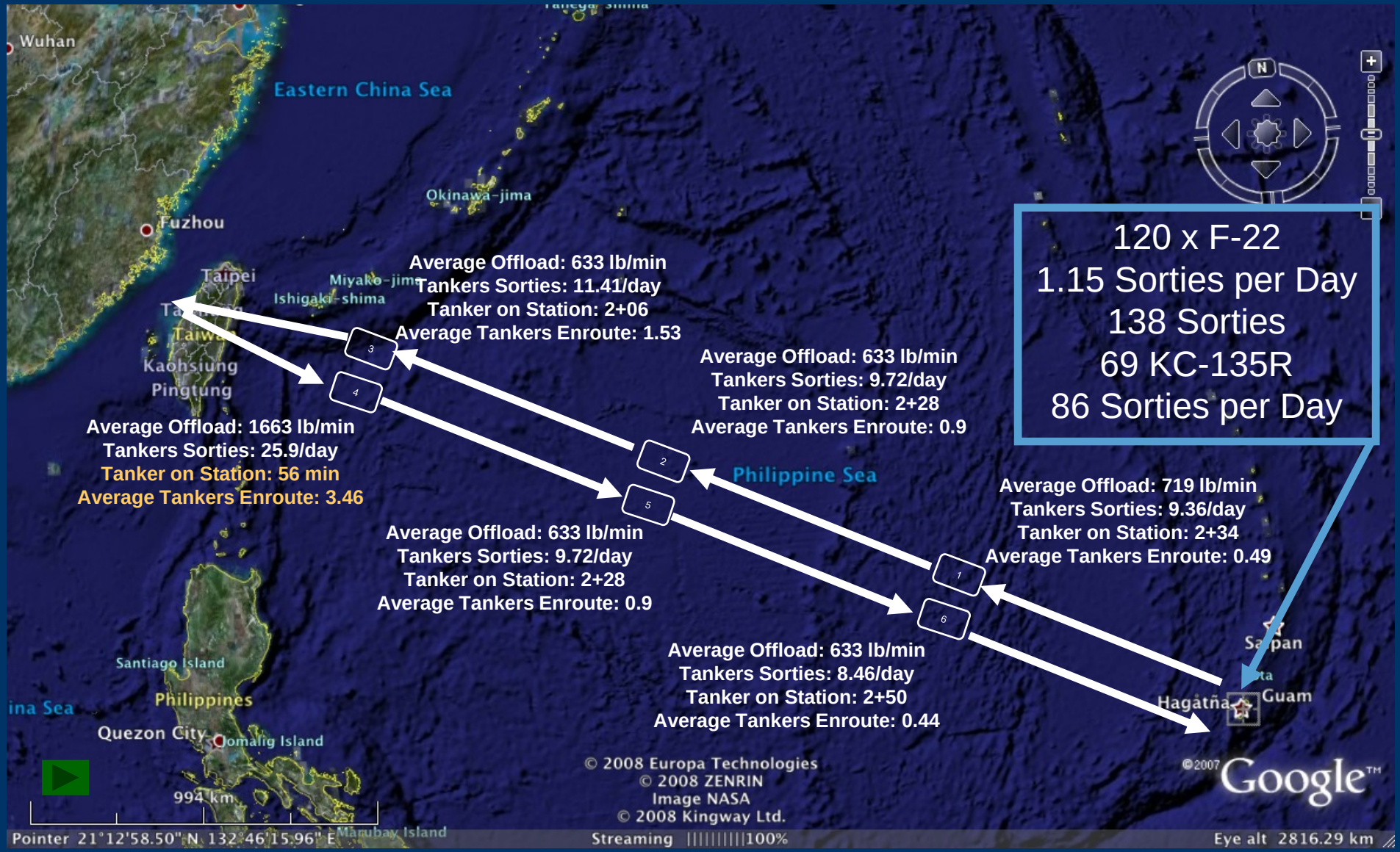
- MiG-15 was ruggedly built
  - Self-sealing fuel tanks
  - Rear armor
  - Thick bullet-proof windscreen
  - Jet engine much less vulnerable to battle damage than piston engines of WWII fighters
  - Kerosene-based jet fuel less likely to ignite when hit than gasoline
  - In interviews after the end of the Cold War Yevgeni Pepelyaev, successful MiG-15 pilot of the Korean War stated:

    The US Browning .50-calibre guns bounced off our aircraft like peas! It was routine for our aircraft to return home having taken forty or fifty hits.
  - One crash landed with 200+ hits and was repaired and back in the air in 8 days

- Postwar USAF study concluded:
  - On average an F-86 needed to fire 1,024 M-3 machine gun rounds to kill a MiG-15
    - About 64 percent of an F-86's normal ammunition load
    - Required just over 8.5 seconds for 6 M-3 machine guns to fire 1,024 rounds

- Bottom line – lots of MiG-15s were hit, damaged and seemed to fall from the sky, but lived to fight another day

Fuel consumption to support F-22s 2.6 million gallons per day vs. 2.2 million gallon per day long term constraint

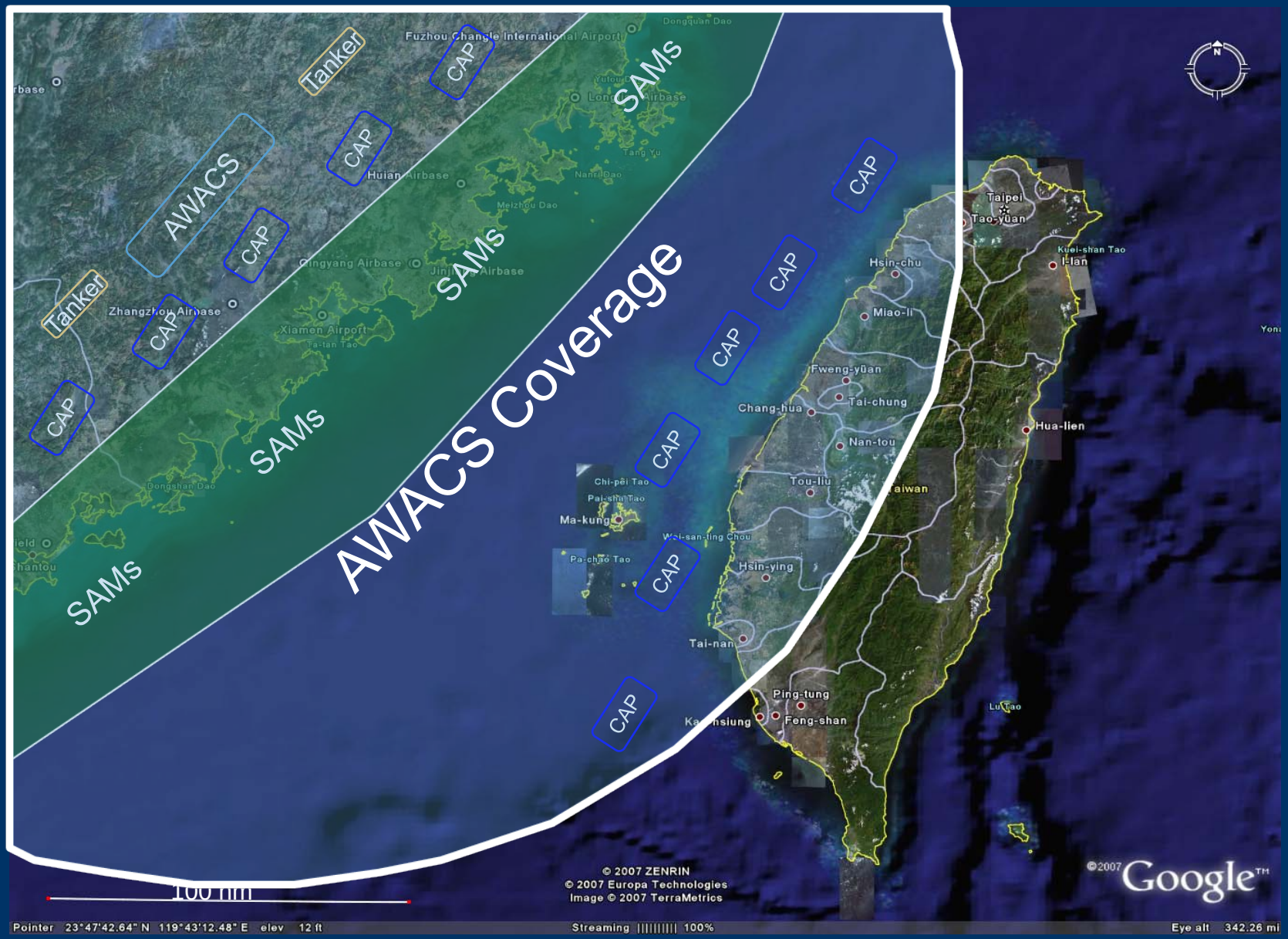


RAND

Air Combat PPF 88

Must launch 3 to 4 tanker sorties per hour to service airborne fighters

Possible Offensive Operations Scheme – Top View



Attacking PLAAF Bases Circa 2020

SA-15D

J-10

SA-21

J-11

RAND