USAF Strike Fighters

An analysis of range, stamina, turning, and acceleration

By "Spurts"

The Contenders

- There are currently slated to be three USAF strike aircraft in the 2020 timeframe
  - F-15E Strike Eagle
    - One of the largest and heaviest fighter aircraft
    - Massive fuel/weapons capacity
  - F-16C Fighting Falcon
    - One of the smallest and lightest fighter aircraft
    - Diminutive fuel capacity, but retains over half the weapons capacity of the F-15E
  - F-35A Lightning II
    - External dimensions similar to F-16, but weight similar to F-15C
    - Tremendous internal fuel/weapon capacity for its size
  - Will also look at F-16C with conformal fuel tanks (referenced as F-16I)

Specs

	F-15E	F-16C	F-16I	F-35A
Empty weight	38,700 lb	20,300 lb	22,300 lb	29,400 lb
Box volume (LxWxH)	50,517 ft^3	25,898 ft^3	25,898 ft^3	25,546 ft^3
Fuel				
Internal	22,300 lb	7,000 lb	10,200 lb	18,200 lb
External	12,000 lb	7,000 lb	7,000 lb	5,800 lb
	3 x 600-gal tanks on heavy stations	2 x 370-gal tanks on heavy stations 1 x 300-gal tank on centerline station	2 x 370-gal tanks on heavy stations 1 x 300-gal tank on centerline station	2 x 428-gal tanks on external heavy stations
Wing Area	608ft^2	300ft^2	300ft^2	460ft^2
Engines	2 x F100-PW-229	F100-PW-229	F100-PW-229	F135-PW-100
T mil	35,600 lbf (17,800 ea)	17,800 lbf	17,800 lbf	28,000 lbf
T ab	58,320 lbf (29160 ea)	29,160 lbf	29,160 lbf	43,000 lbf
TSFC mil	.76	.76	.76	.886
Length / Diameter (in)	191 / 46.5	191 / 46.5	191 / 46.5	220 / 46
BPR	.36	.36	.36	.57

Specs

	F-15E	F-16C	F-16I	F-35A
Air to Air	8	6	6	16
AIM-120	8	6	6	14
	1 ea on 4 CFT heavy stations	1 ea on outer heavy station	1 ea on outer heavy station	2 ea per heavy station (2 internal, 4 external)
	2 ea on dedicated wing pylon AAM station	1 ea on 4 dedicated AAM stations	1 ea on 4 dedicated AAM stations	1 ea on dedicated internal AAM station
AIM-9	4	6	6	10
	2 ea on dedicated wing pylon AAM station	1 ea on outer heavy station	1 ea on outer heavy station	2 ea per heavy station (4 external)
		1 ea on 4 dedicated AAM stations	1 ea on 4 dedicated AAM stations	1 ea on dedicated external AAM station
Air to Ground, heavy stations	7	4	4	6
	One under each wing	Two under each wing	Two under each wing	Two under each wing
	One on centerline			One in each internal bay
	Two on each CFT			
Targeting Pods	External under intakes	External under intake	External under intake	Internal under nose

Specs – conclusion

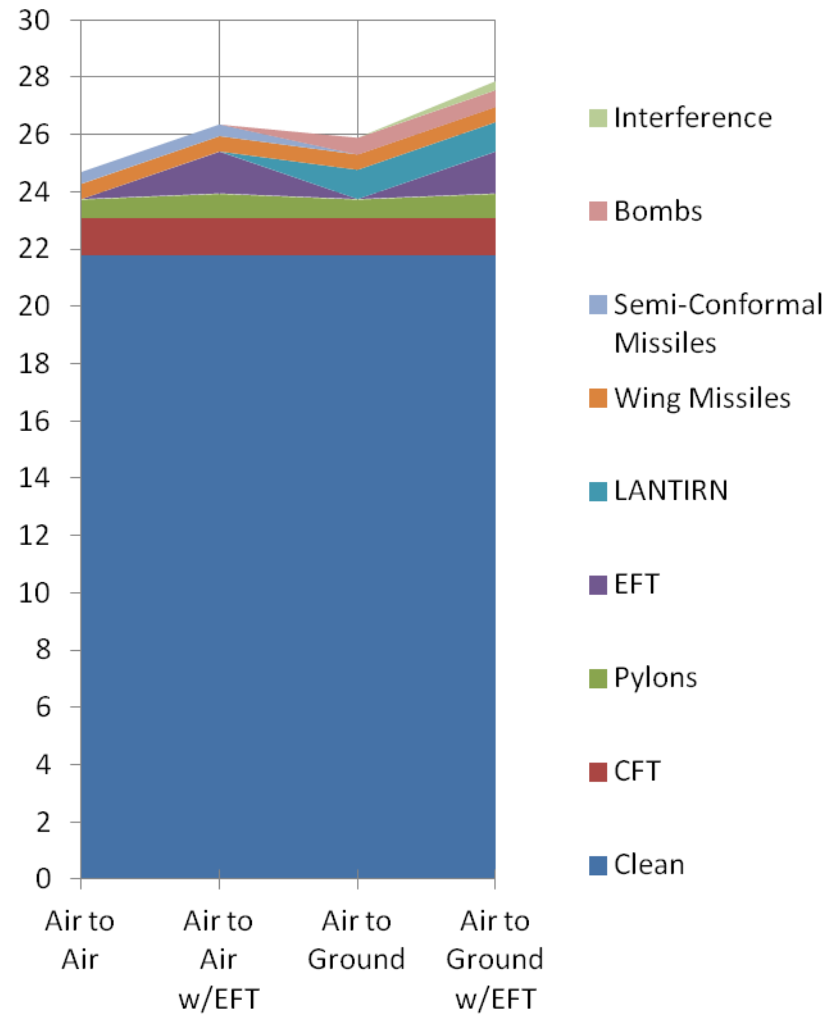
- The considerable empty weight of the dimensionally small F-35 is accounted for by its internal carriage of large fuel volumes, two heavy A2G stations, two A2A stations, and Targeting equipment
- Despite the F-35 only having 4 dedicated AAM stations, the ability to carry two missiles per heavy station gives it vast flexibility

Stability and effective Lift Area

- From the official F-15E stall speed charts it can also be calculated that the maximum effective Coefficient of Lift (C_{lmax}) is 1.24. Multiplying this and the wing area of $608ft^2$ together we see that the maximum effecting Lift Area is 1.24*608=$754ft^2$
- The F-15E is stable by ~27% MAC. This means the center of gravity is roughly 4ft in front of the aerodynamic center.. Without outside action, under positive load the nose would fall. This is countered by a downward force by the horizontal stab, whose local aerodynamic center is roughly 20ft behind the C.G. As the H. Stab is five times farther from the C.G. than the wing it needs to make 1/5 the load to balance. The Wing must then balance that load equally. As such for any net lift there is an additional gross lifting action equal to 40% of the net lift. This additional lift/counter-lift still makes induced drag. As induced drag is a function of the square of lift we can estimate that a 40% increase in lift is a 96% increase in induced drag, or roughly double. Additionally we can see that if the F-15 was to be neutrally stable (no steady state load needed from the H. Stab) that at the same angle of attack it's total lift would increase by 20% to 1.49 (and an area of $905ft^2$. Any degree of instability would increase the net lift available as the tail would incrementally add to the total force. For calculation purposes this represents an increase to C_{LMax}.
- The F-16 is slightly unstable, meaning that the H. Stabs do not provide a negative lift, but instead a positive to neutral lift. What this means relative to the previous calculation is that all gross lift is net lift. The F-16 however is unique in its flight control laws in that it cannot achieve the AoA for best lift unless it is at 1G flight and it instead follows a decrementing system until it reaches 9G. This is called the CAT-I limiter. There is also a more restrictive CAT-III limiter for air to ground loads. A high-fidelity computational fluid dynamic model of the F-16 gives it a C_{lmax} of 1.7 at 25 degrees AoA. Assuming this is linear down to 15 degrees (highest AoA for 9G) then the C_{lmax} for 9G would be 1.02. The max effective Lift Area thus varies between $306ft^2$ and $510ft^2$
- Given the wider fore-body and larger tail (relative to the F-16) I estimate the F-35 needs more tail lift than the F-16, which will be represented by a C_{lmax} to be 1.8. This leads to a maximum Lift Area of 828ft^2
- All turning data for the F-15 and F-16 will come from charts generated from flight test data while the F-35 data must be estimated through calculation for each point.

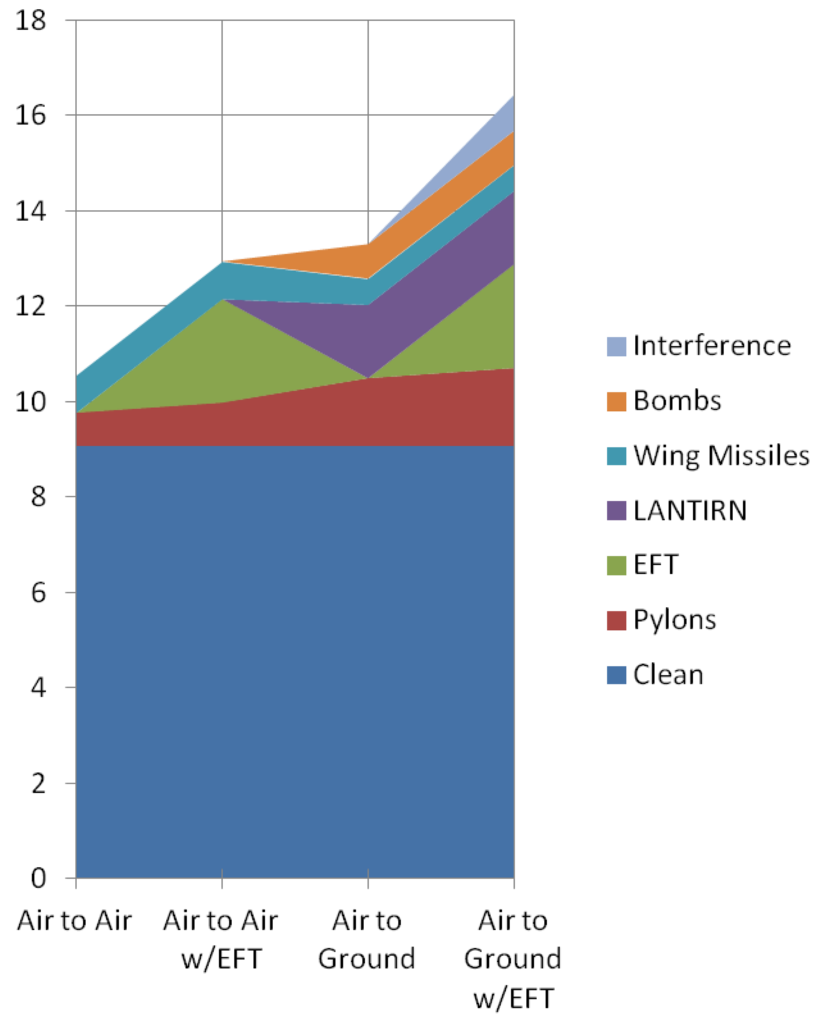
Stores and effective Drag Area

- Drag Areas are estimated by the max endurance fuel flow and an estimation of the dynamic value of listed engine TSFC (fuel burn)
- Drag Index is airframe specific as it measures a change to the Drag Coefficient (1 DI = .0001 C_{D0})
- The F-15E Has an Estimated CD0 of 0.0358 for a Drag Area (DA) of 0.0358*608ft^2=21.78ft^2
  - The Air to Air loading gives 47.9 DI
    - CFTs – 21.3 DI
    - Suspension equipment – 11 DI
    - Wing mounted missiles
      - Two-AIM-9X – 4.2DI
      - Two AIM-120B – 4.6 DI
    - Four Semi-Conformal AIM-120Bs - 6.8 DI
  - Adding EFT Increases DI by 27.5 for three 600-gal fuel tanks and additional centerline pylon
  - The Air to Ground loading gives 67.8 DI
    - Semi-Conformal AIM-120s replaced by two GBU-31s – 9.8 DI
    - LANTIRN system – 16.9 DI
  - Adding EFT Increases DI by 32.6 due to interference drag between the bombs and fuel tanks
  - The chart to the left shows how due to the sheer size of the F-15E even the heaviest of loads impose a relatively small drag penalty



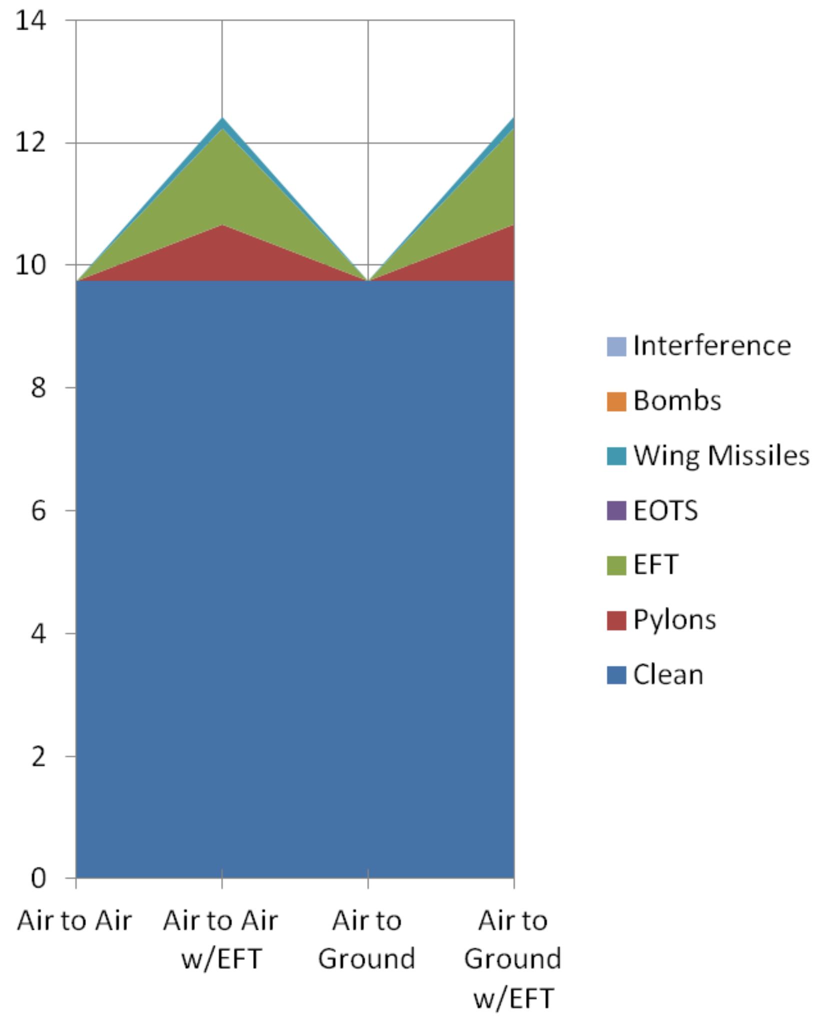
Stores and effective Drag Area

- Drag Areas are estimated by the max endurance fuel flow and an estimation of the dynamic value of listed engine TSFC (fuel burn)
- Drag Index is airframe specific as it measures a change to the Drag Coefficient (1 DI = .0001 C_{D0})
- The F-16C Has an Estimated CD0 of 0.0302for a Drag Area (DA) of 0.0302*300ft^2=9.07ft^2
  - The Air to Air loading gives 50 DI
    - Suspension equipment – 24 DI
    - Wing mounted missiles
      - Two-AIM-9X – 10 DI
      - Four AIM-120B – 16 DI
  - Adding EFT Increases DI by 79 for two 370-gal fuel tanks, a 300-gal fuel tank and additional centerline pylon
  - The Air to Ground loading gives 141 DI
    - Two wing mounted AIM-120 replaced by two GBU-31s – 24 DI
    - LANTIRN system – 51DI
  - Adding EFT Increases DI by 104 due to interference drag between the bombs and fuel tanks
  - The chart to the left shows how due to the small size of the F-16C, even light loads add significant drag.
  - The F-16I has a clean drag only 0.21ft^2 higher than the F-16C and has all the same stores DI values

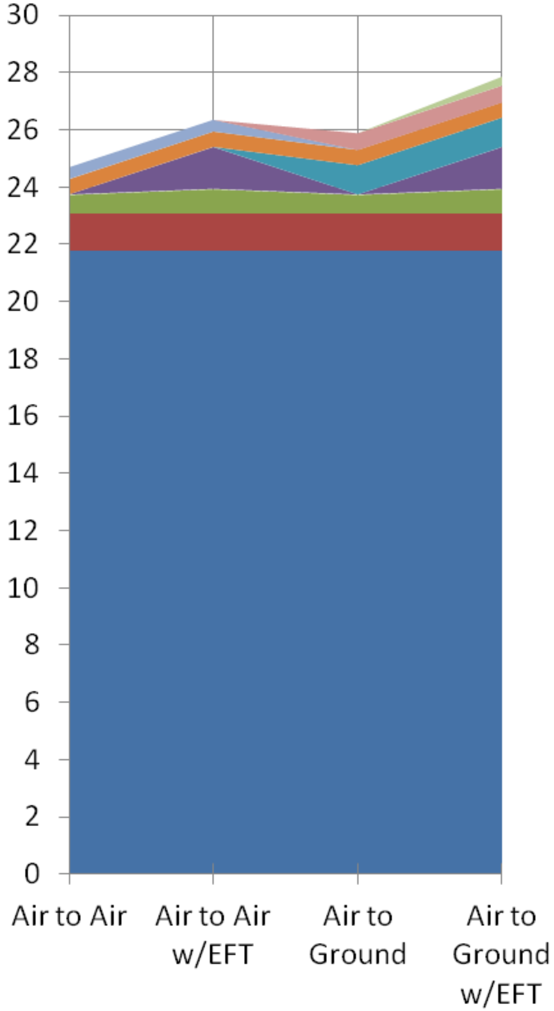


Stores and effective Drag Area

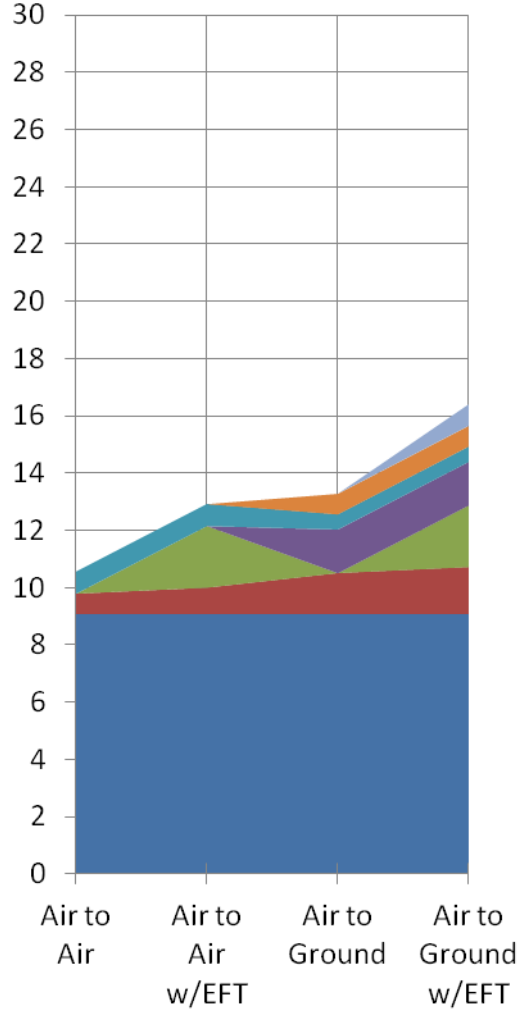
- Drag Areas are estimated by the max endurance fuel flow and an estimation of the dynamic value of listed engine TSFC (fuel burn)
- Drag Index is airframe specific as it measures a change to the Drag Coefficient (1 DI = .0001 C_{D0})
- The F-35A Has an Estimated CD0 of 0.0212for a Drag Area (DA) of 0.0212*460ft^2=9.75ft^2
  - The Air to Air loading gives 0 DI
  - Adding EFT Increases DI by 58 for two 428-gal fuel tanks and two external AIM-9Xs
  - The Air to Ground loading gives 0 DI
  - Adding EFT Increases DI by 58 for two 428-gal fuel tanks and two external AIM-9Xs
  - The chart to the left shows how the addition of external tanks and pylons are the only things that effect the F-35As drag and it is otherwise a very slick aircraft



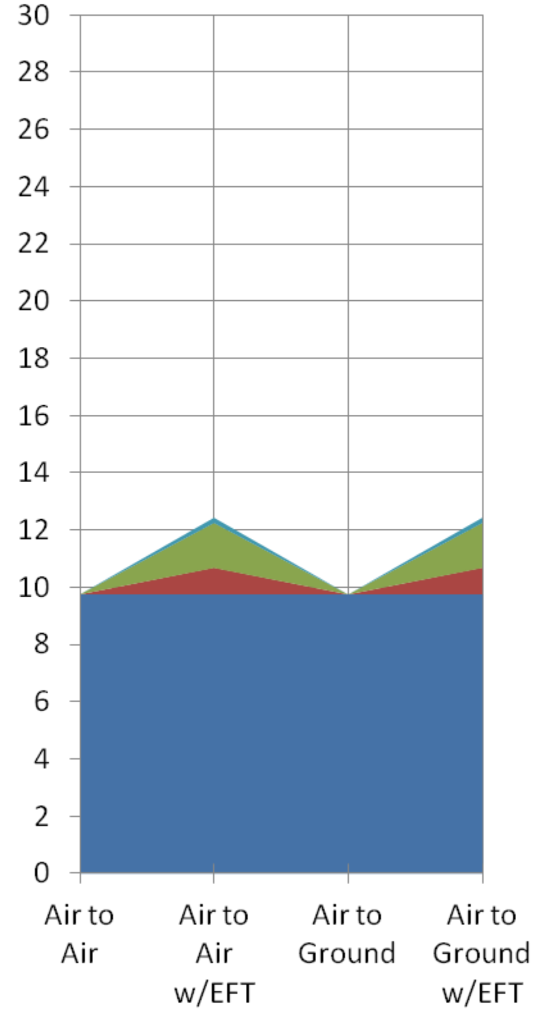
F-15E



F-16C



F-35A



Drag – conclusion

- Despite the natural low drag of the F-16 airframe the addition of missiles, bombs, pylons, tanks, and targeting pods nearly doubles its base drag.
- The low drag of the F-35 will allow for higher cruise speeds and/or greater range, the two being a natural tradeoff.
- The drag areas of the clean F-16 and F-35 are consistent with the story of an F-35 with 9 tons of internal fuel/weapons (traditional T/W of .59) out climbing the F-16 chase plane that was carrying only a centerline gas tank (traditional T/W of .61) while in military power.

Missions

500nm Endurance

- If tanks are carried then they are assumed to be carried throughout mission
- Assumed time/performance critical target appears as soon as aircraft is on station (most fuel remaining, worst performance)
  - Tanks are dropped
  - Instant/Sustained turn taken at cruise speed
  - Cruise Speed to 1.2M acceleration measured

Additional factors

- Max Range calculated as alternate mission plan
- Two flight profiles calculated
  - Optimum max range profile
  - Mission dictated 20,000ft at 0.8M

Cruise

- Under Optimum Cruise conditions an aircraft maintains a constant speed a bit faster than its speed for maximum endurance and as fuel is burned off the aircraft climbs.
- Drag will primarily determine the cruise speed and weight will determine the altitude
- Altitude shift is only measured for the outbound 500nm portion

Air to Air Loading

- The F-15E carries four AIM-120Bs on it's conformal fuel tanks. It also has its wing pylons that each carry one AIM-9X and one AIM-120B
  - When EFTs are added, one 600-gal tank goes on each wing pylon and one 600-gal tank goes on the centerline with the addition of an extra pylon.
- The F-16C carries one AIM-120B on each wingtip and one AIM-9X and AIM-120B under each wing on small pylons
  - When EFTs are added one 370-gal tank is added to each wing and one 300 gallon tank is added to the centerline with the associated pylons.
- The F-35A carries one AIM-120D on each bays dedicated Air to Air station and two AIM-120Ds on each bays Air to Ground station (as this is assumed to be in the 2020 timeline)
  - When EFTs are added one 428-gal tank goes under each wing and one AIM-9X is added under each wing with associated pylons

500nm CAP

- Altitude with Distance

Assumptions:

All aircraft are able to top off at the tanker right at their optimum altitudes.

Notes:

Cruise Speeds:

F-16C/CFT (EFT) - .84/.84 (.83/.82)

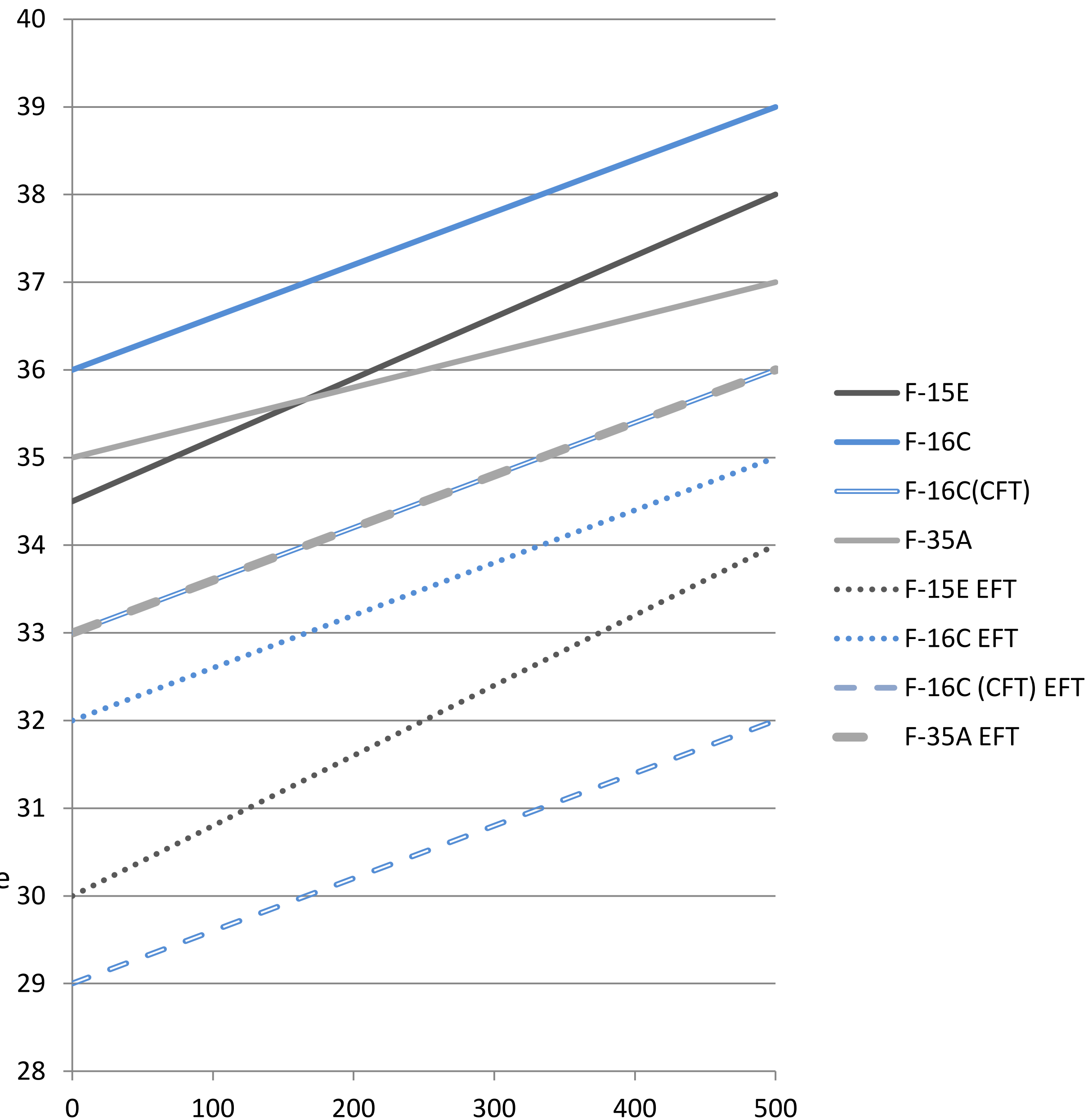
F-15E (EFT) - .87(.85)

F-35A (EFT) - .87(.85)

The added weight of extra fuel (CFT and/or EFT has a huge impact on best cruise altitude

F-35A with EFT has same cruise altitudes as F-16C with CFT

For non-optimum cruise all aircraft are traveling at 0.8M at 20,000ft.



Endurance

- For the Endurance calculations nothing is assumed to be dropped. With EFTs carried this represents worst-case scenarios as the extra drag is carried for the duration.
- The following fuel data shows the fuel burned during the 500nm cruise, followed by the fuel required to make a 500nm return to the tanker, followed by the fuel remaining for the CAP, all in lb.
- Despite the modest increase of drag between the F-16I and the F-16C the drastic increase in weight impacts the fuel burn and altitude.
- Despite the large increase in fuel remaining when the F-35A carries EFTs the change in fuel burn means it does not carry over into endurance. Either the current 428-gal tanks have far lower drag than EFTs of the past or they are a waste of time.

		F-15E	F-16C	F-16I	F-35A
Optimum	Ingress	7,042 lb	2,882 lb	3,546 lb	5,435 lb
	Egress	5,634 lb	2,532 lb	2,924 lb	4,630 lb
	CAP	8,639 lb	1,037 lb	3,250 lb	7,386 lb
Optimum EFT	Ingress	9,302 lb	4,255 lb	4,950 lb	6,786 lb
	Egress	6,250 lb	3,175 lb	3,610 lb	5,714 lb
	CAP	17,763 lb	6,092 lb	8,231 lb	10,770 lb
20,000ft	Ingress	9,165 lb	4,023 lb	4,211 lb	7,915 lb
	Egress	8,642 lb	4,011 lb	3,963 lb	7,162 lb
	CAP	4,008 lb	-1,584 lb	1,546 lb	2,373 lb
20,000ft EFT	Ingress	10,728 lb	4,886 lb	5,462 lb	10,080 lb
	Egress	10,117 lb	4,525 lb	4,970 lb	8,994 lb
	CAP	13,210 lb	4,111 lb	6,360 lb	5,196 lb

500nm CAP Endurance (min)

Assumptions:

Optimum cruise data assumes constant climb as fuel is burned and all missiles are retained.

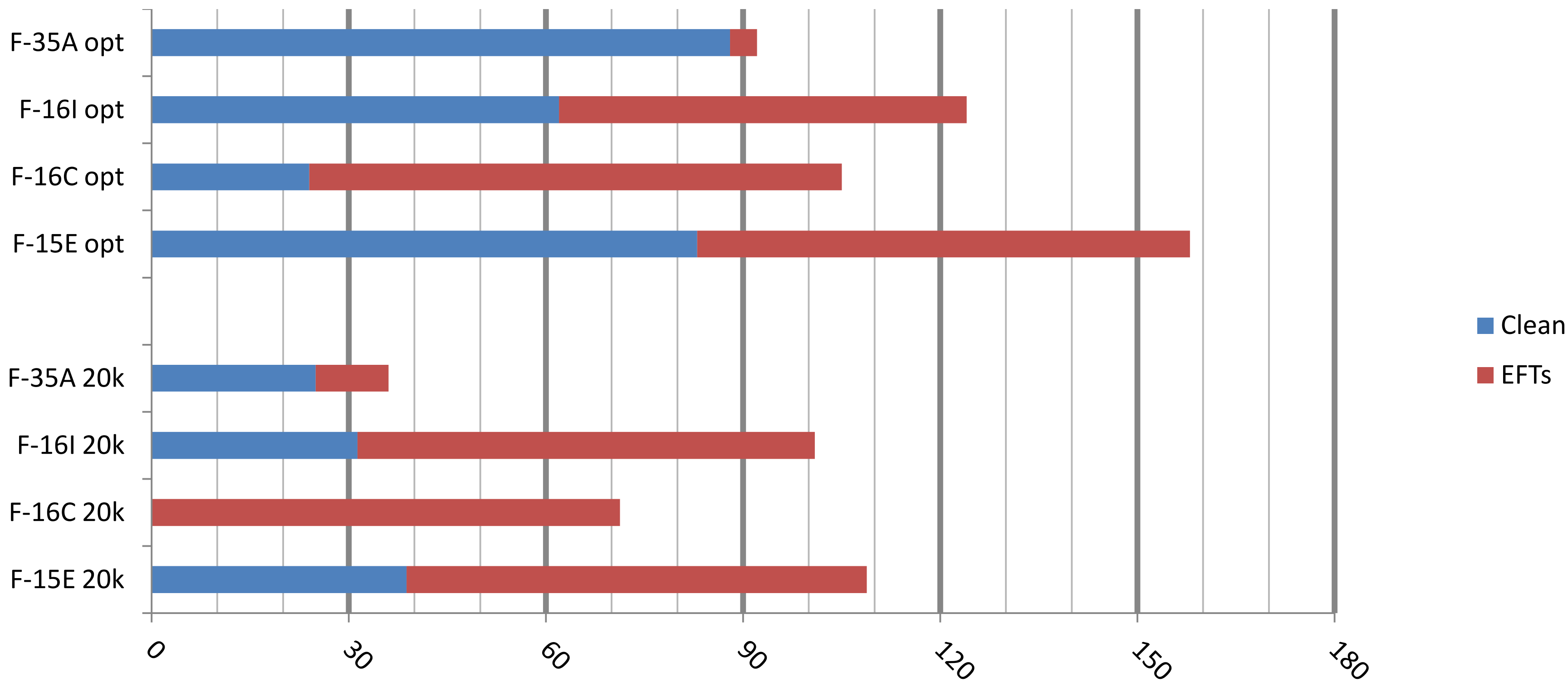
EFTs are retained for entire mission

Notes:

Under Optimum Cruise, the F-35 can loiter longer while clean than even a Strike Eagle.

Under a constrained flight plan most of the aircraft have around 30 minutes of clean endurance. The F-16C **cannot** make a 500nm cruise at 20kft without drop tanks

The two 428 gallon drop tanks on the F-35A provide such a small increase in fuel fraction but increase drag by about 27% The F-35 is the only aircraft that is out of fuel in the external tanks before reaching 500nm.



Dogfight 500nm out

Assumptions:

Aircraft get bounced as soon as they are on station, the most fuel on board gives the worst performance. Any EFTs are dropped.

Notes:

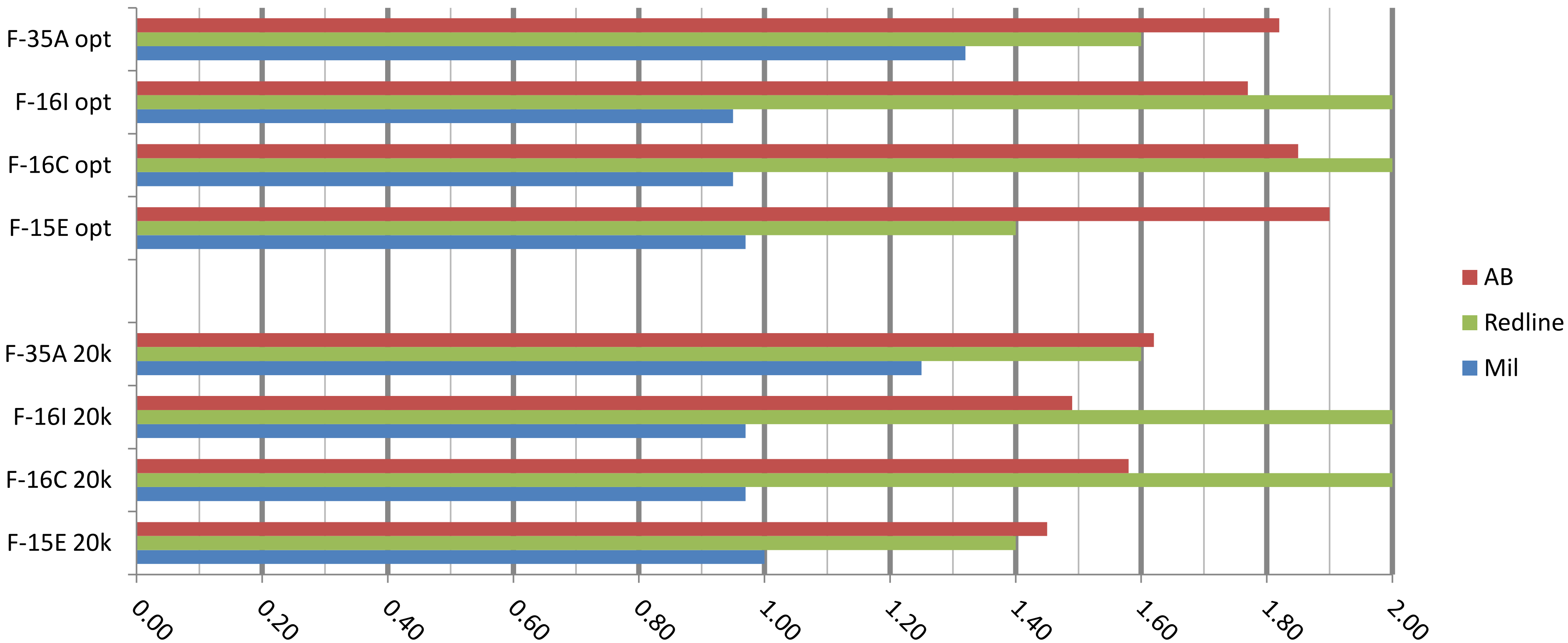
The F-16 has very high placard limits under air to air loading and is drag limited.

The F-15E is placard limited to 1.4M whenever a load is carried on the CFTs, which is always.

The F-15E and F-35 have more thrust than their placard limits allow.

The F-35s placard limit is often above the placard/thrust limits of its brethren, only A-A configured F-16 are faster and only at higher altitudes.

- Speed (Mach)



Dogfight 500nm out

Assumptions:

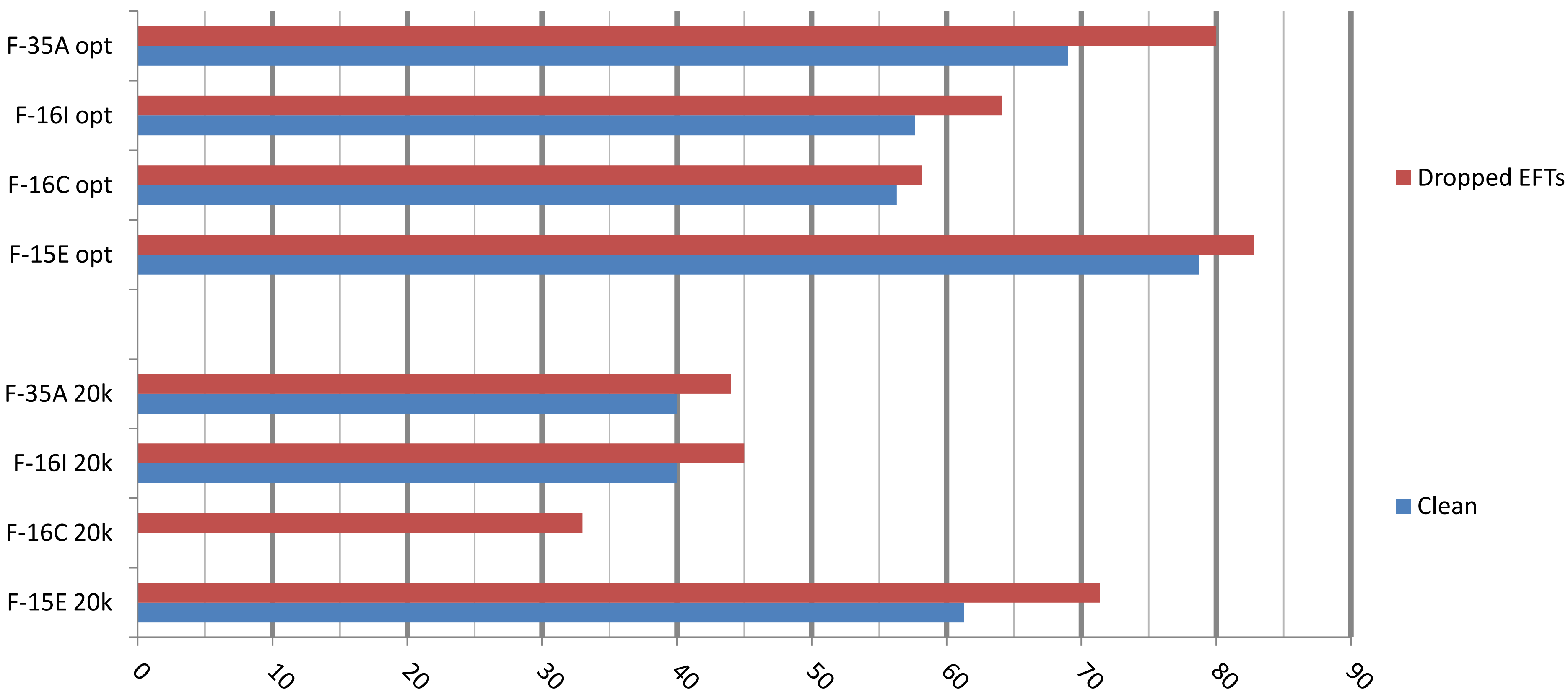
Aircraft get bounced as soon as they are on station, the most fuel on board gives the worst performance. Any EFTs are dropped.

Notes:

In Optimum Cruise scenarios the added weight of the extra fuel in the dropped EFT group is mitigated by the lower altitude.

0.8-1.2M acceleration, while one of the standard JSF parameters, is rather arbitrary if flown at Optimum Cruise as it starts out between .84 and .87 depending on aircraft

- Cruise-1.2M acceleration (sec)



Dogfight 500nm out

Assumptions:

Aircraft get bounced as soon as they are on station, the most fuel on board gives the worst performance. Any EFTs are dropped.

Notes:

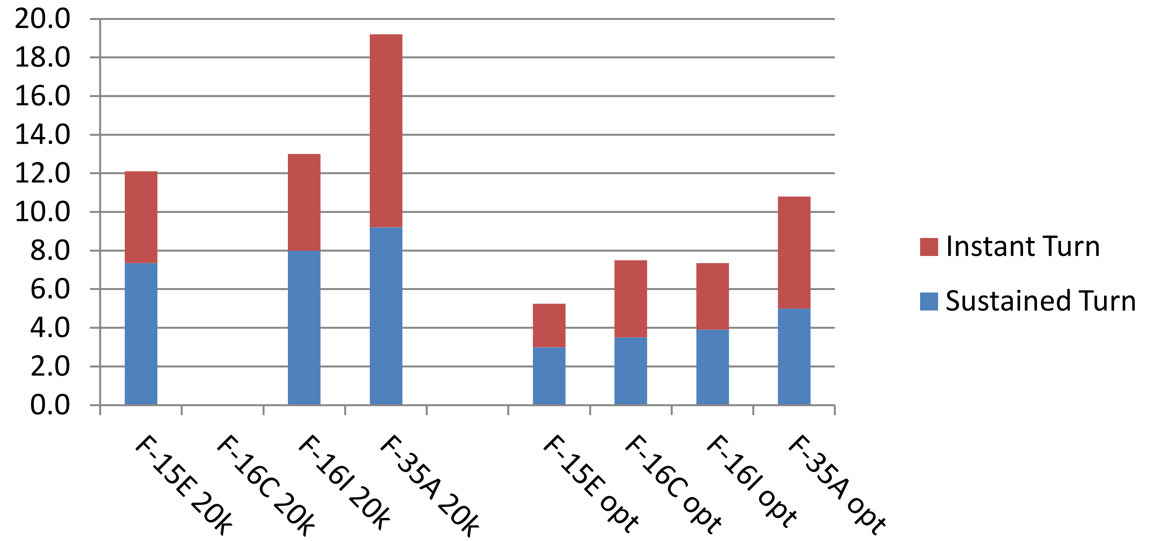
In Optimum Cruise scenarios the added weight of the extra fuel in the dropped EFT group is mitigated by the lower altitude.

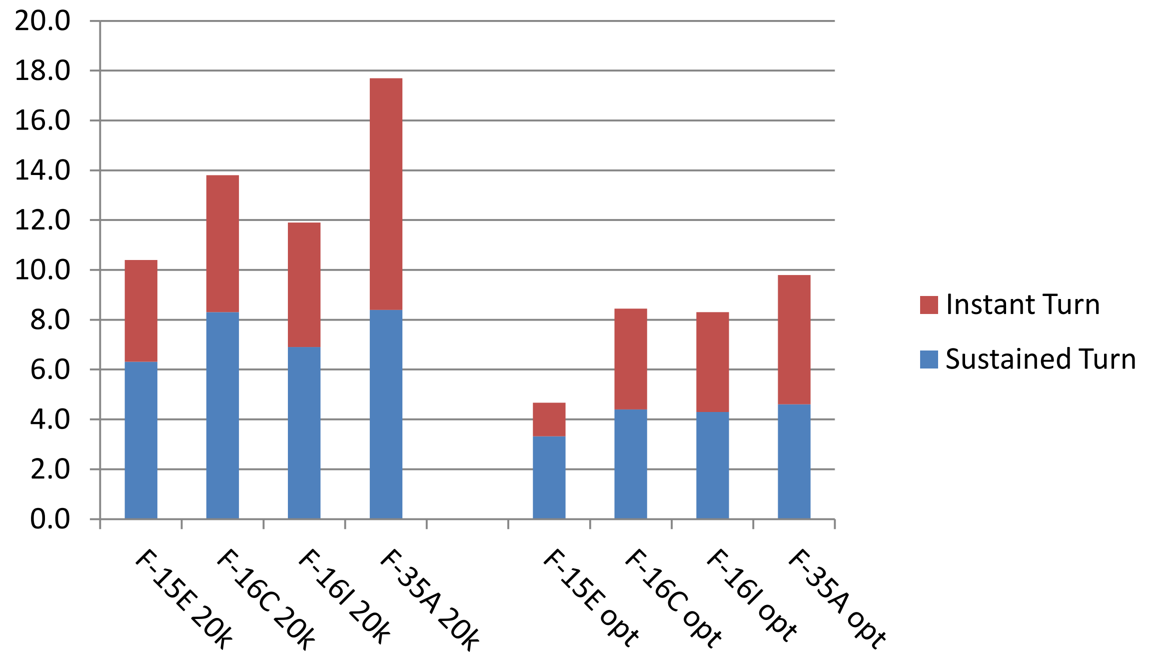
All aircraft are lift limited in these scenarios with the exception of the F-35 at 20kfeet and 0.8M in which it is right at corner velocity.

Data found coincides with statements of “Sustained Turns similar to F-16 with Instantaneous Turns similar to F/A-18”. While lift limited the F-35 can out point the F-16 at the expense of energy.

This is a true apples-apples mission based performance, not “50% fuel with two AIM-120s”

- Turn rate at cruise speed (clean above dropped EFTs) in Deg/sec





“Osirak” style escort mission

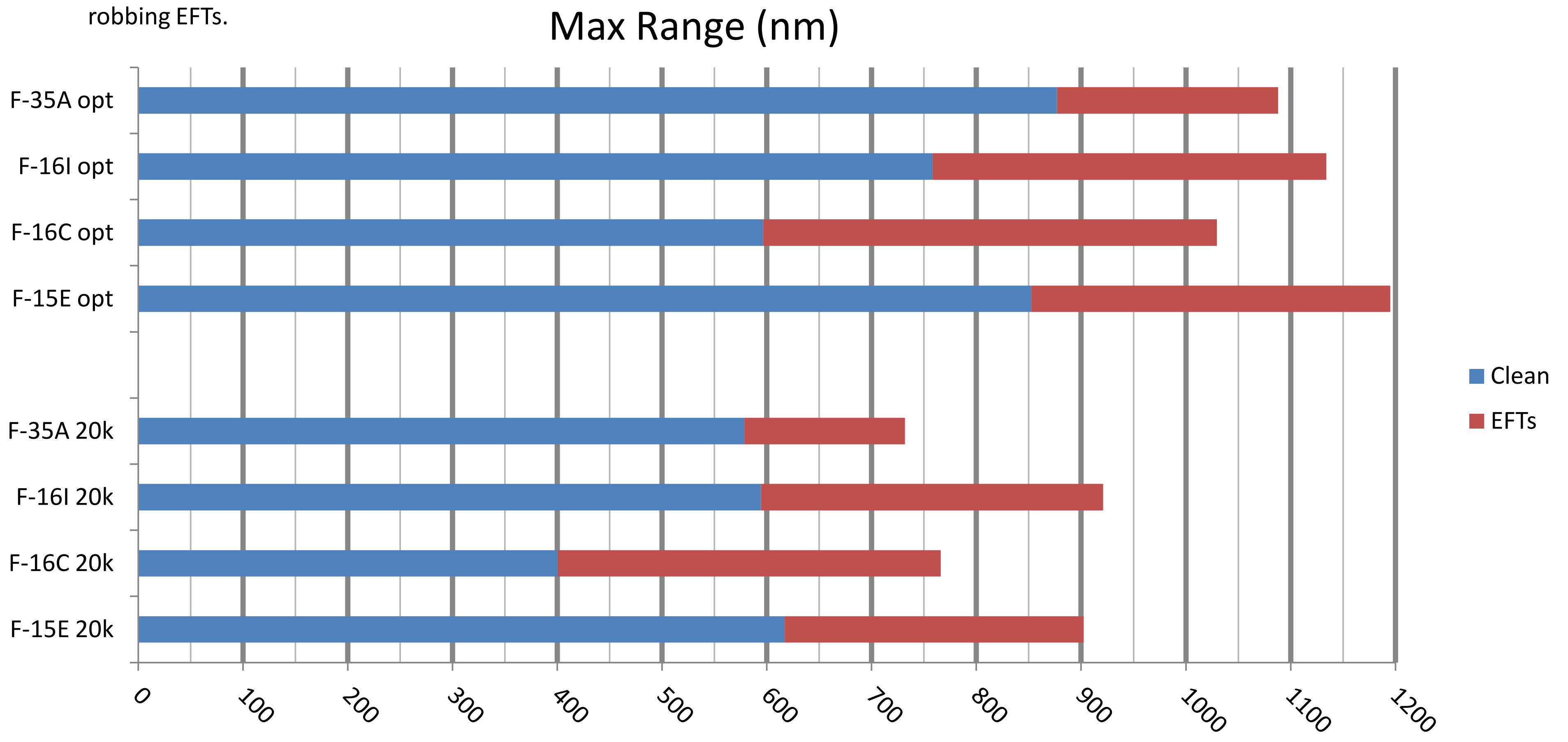
Assumptions:

EFTs are dropped as soon as they are empty

Notes:

The Constrained Flight Plan at 20,000ft shows results similar to the number compared to the KPP, but we can see that no clean strike aircraft is going to significantly exceed that range.

While the F-16 is a hotrod in acceleration, it suffers greatly in range compared to the heavier aircraft without performance robbing EFTs.



Air to Ground Loading

- The F-15E carries two GBU-31s on it’s conformal fuel tanks. It also has its wing pylons that each carry one AIM-9X and one AIM-120B
  - When EFTs are added, one 600-gal tank goes on each wing pylon and one 600-gal tank goes on the centerline with the addition of an extra pylon.
- The F-16C carries one AIM-120B on each wingtip and one AIM-9X and GBU-31 under each wing on pylons
  - When EFTs are added one 370-gal tank is added to each wing and one 300 gallon tank is added to the centerline with the associated pylons.
- The F-35A carries one AIM-120D on each bays dedicated Air to Air station and one GBU-31 on each bays Air to Ground station
  - When EFTs are added one 428-gal tank goes under each wing and one AIM-9X is added under each wing with associated pylons

500nm Interdiction

Assumptions:
All aircraft are able to top off at the tanker right at their optimum altitudes.

Notes:

Cruise Speeds:

F-16C/CFT (EFT) - .83/.81 (.80/.80)

F-15E (EFT) - .86(.83)

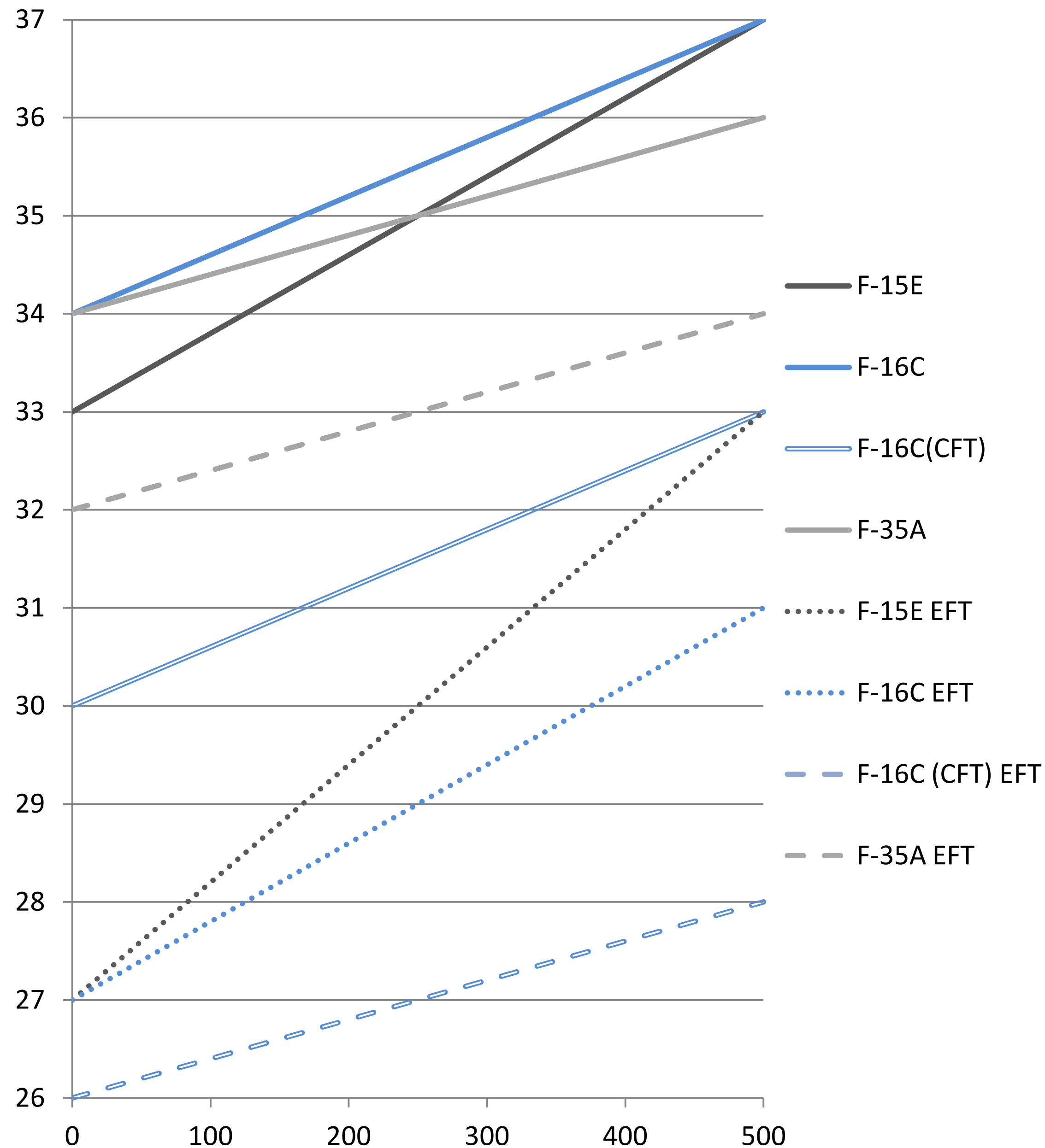
F-35A (EFT) - .87(.85)

The added weight of extra fuel (CFT and/or EFT has a huge impact on best cruise altitude

The added weight of targeting pods as well as the drag of the targeting pods and bombs (and interference drag between bombs and tanks) robs the 4th Gen aircraft of their performance

For non-optimum cruise all aircraft are traveling at 0.8M at 20,000ft.

- Altitude with Distance



Endurance

- For the Endurance calculations nothing is assumed to be dropped. With EFTs carried this represents worst-case scenarios as the extra drag is carried for the duration.
- The following fuel data shows the fuel burned during the 500nm cruise, followed by the fuel required to make a 500nm return to the tanker, followed by the fuel remaining for the loiter, all in lb.
- Despite the modest increase of drag between the F-16I and the F-16C the drastic increase in weight impacts the fuel burn and altitude.
- Despite the large increase in fuel remaining when the F-35A carries EFTs the change in fuel burn means it does not carry over into endurance. Either the current 428-gal tanks have far lower drag than EFTs of the past or they are a waste of time.

		F-15E	F-16C	F-16I	F-35A
Optimum	Ingress	7,692 lb	3,891 lb	4,608 lb	5,780 lb
	Egress	5,714 lb	2,967 lb	3,279 lb	4,425 lb
	CAP	7,908 lb	-408 lb	1,833 lb	7,245 lb
Optimum EFT	Ingress	11,111 lb	5,797 lb	6,667 lb	7,199 lb
	Egress	6,542 lb	3,676 lb	3,922 lb	5,464 lb
	CAP	15,752 lb	4,048 lb	6,204 lb	10,606 lb
20,000ft	Ingress	10,014 lb	5,184 lb	5,462 lb	8,135 lb
	Egress	9,259 lb	4,456 lb	4,495 lb	7,066 lb
	CAP	2,542 lb	-3190 lb	-237 lb	2,249 lb
20,000ft EFT	Ingress	12,179 lb	6,685 lb	7,052 lb	11,169 lb
	Egress	10,095 lb	5,573 lb	5,648 lb	8,892 lb
	CAP	11,759 lb	2,312 lb	4,770 lb	3,209 lb

500nm Interdiction Endurance (min)

Assumptions:

Optimum cruise data assumes constant climb as fuel is burned and all missiles are retained.

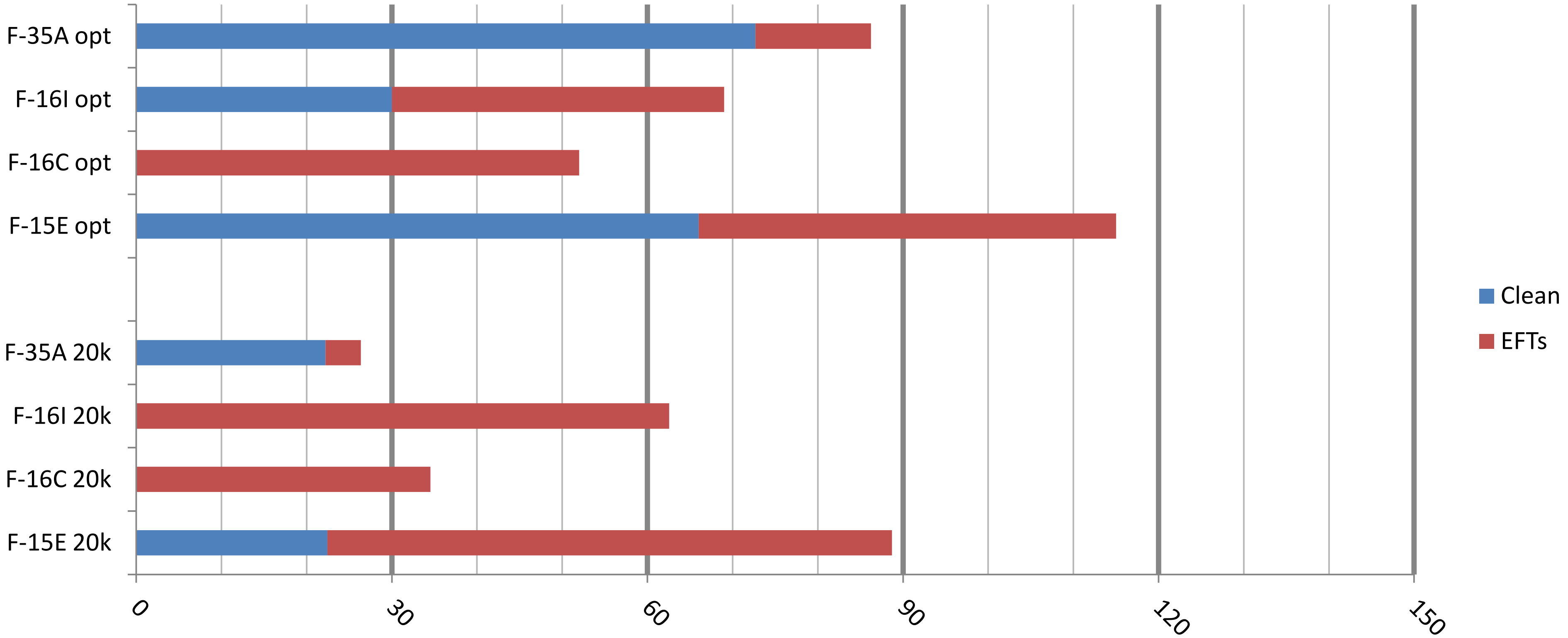
EFTs are retained for entire mission

Notes:

Under Optimum Cruise, the F-35 can loiter longer while clean than even a Strike Eagle.

The F-16C **cannot** make a 500nm cruise at any altitude without drop tanks, adding CFTs still requires an Optimum Cruise.

The two 426 gallon drop tanks on the F-35A provide such a small increase in fuel fraction but increase drag by about 27% The F-35 is the only aircraft that is out of fuel in the external tanks before reaching 500nm.



Dogfight 500nm out

Assumptions:

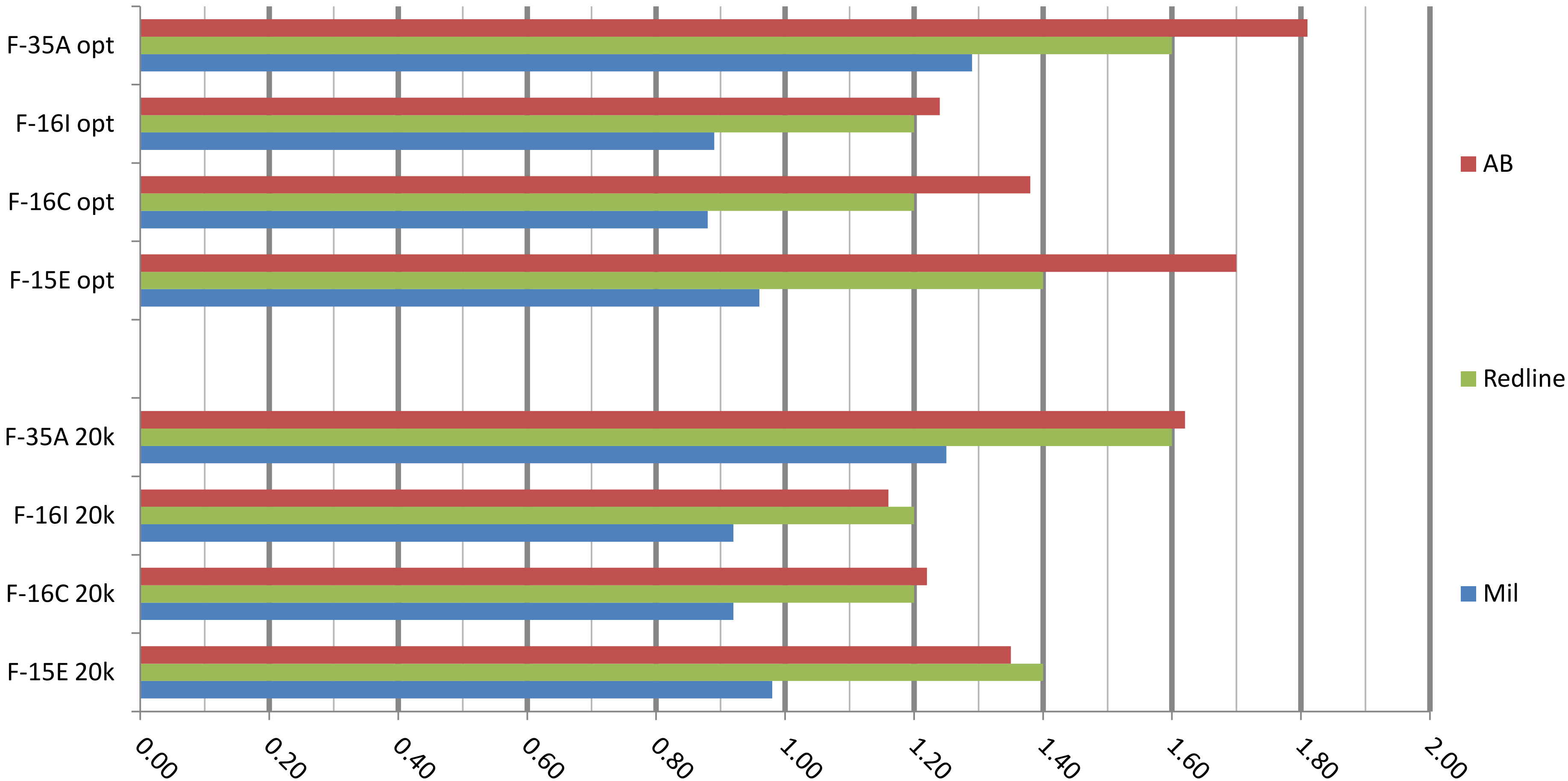
Aircraft get bounced as soon as they are on station, the most fuel on board gives the worst performance. Any EFTs are dropped.

Notes:

Both placard and drag limit speeds are reduced drastically for the F-16

The F-35s is unquestionably the fastest strike aircraft of the group.

- Speed (M)



Dogfight 500nm out

Assumptions:

Aircraft get bounced as soon as they are on station, the most fuel on board gives the worst performance. Any EFTs are dropped.

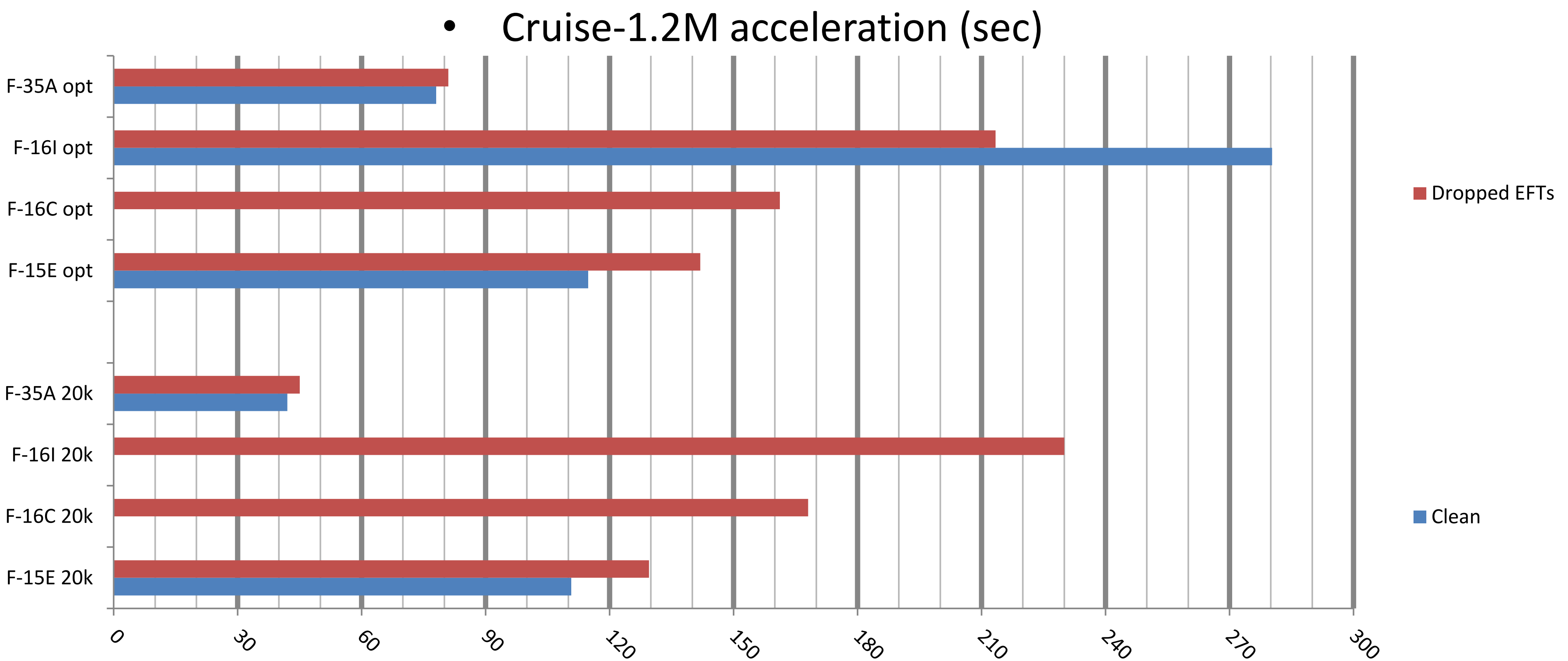
Notes:

In Optimum Cruise scenarios the added weight of the extra fuel in the dropped EFT group is mitigated by the lower altitude.

0.8-1.2M acceleration, while one of the standard JSF parameters, is rather arbitrary if flown at Optimum Cruise as it starts out between .80 and .87 depending on aircraft

F-16 with CFT cannot reach 1.2M at 20kft, time listed is to reach 1.17M

Compared to A-A loadouts, the F-35 goes from competitive to the hotrod of the group while the previous hotrod is pushing its drag limits



Dogfight 500nm out

Assumptions:

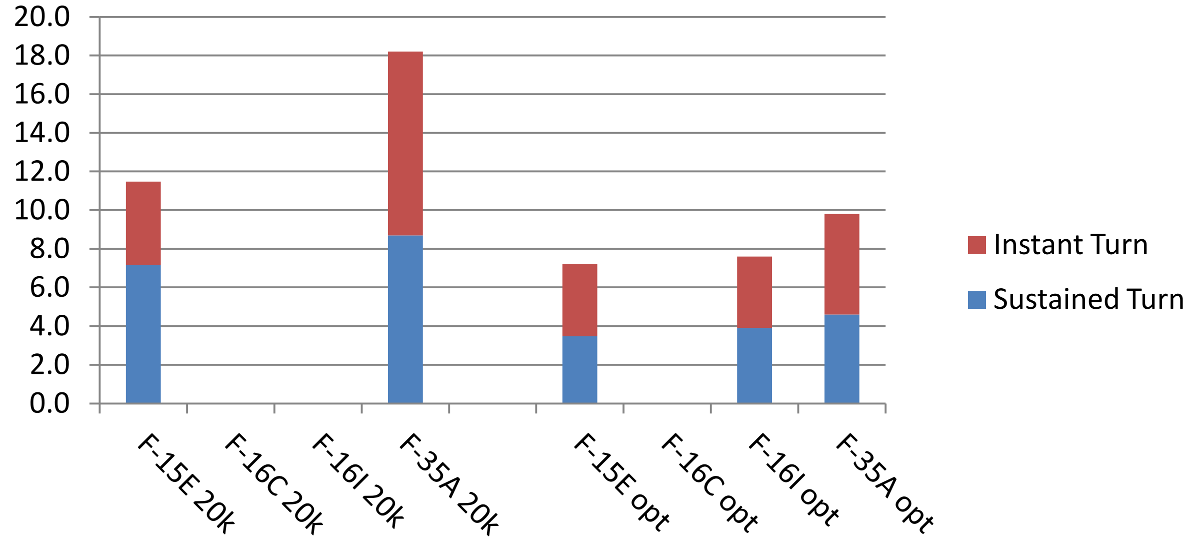
Aircraft get bounced as soon as they are on station, the most fuel on board gives the worst performance. Any EFTs are dropped.

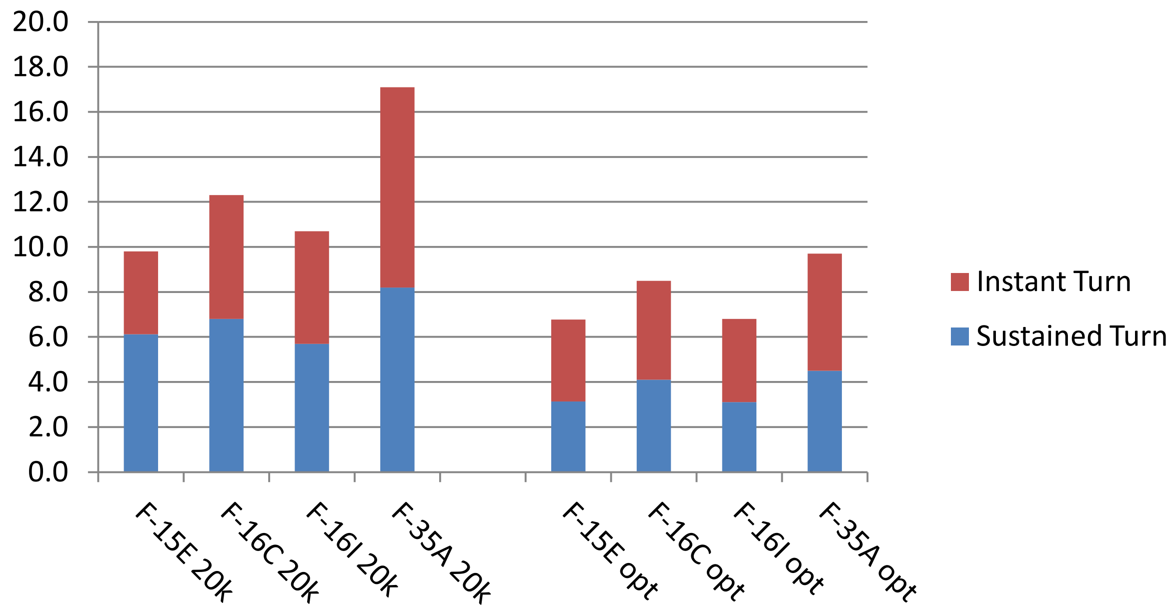
Notes:

In Optimum Cruise scenarios the added weight of the extra fuel in the dropped EFT group is mitigated by the lower altitude.

All aircraft are lift limited in these scenarios with the exception of the F-35 at 20kfeet and 0.8M in which it is right at corner velocity.

- Turn rate at cruise speed (clean above dropped EFTs) in Deg/sec





“Osirak” style strike mission

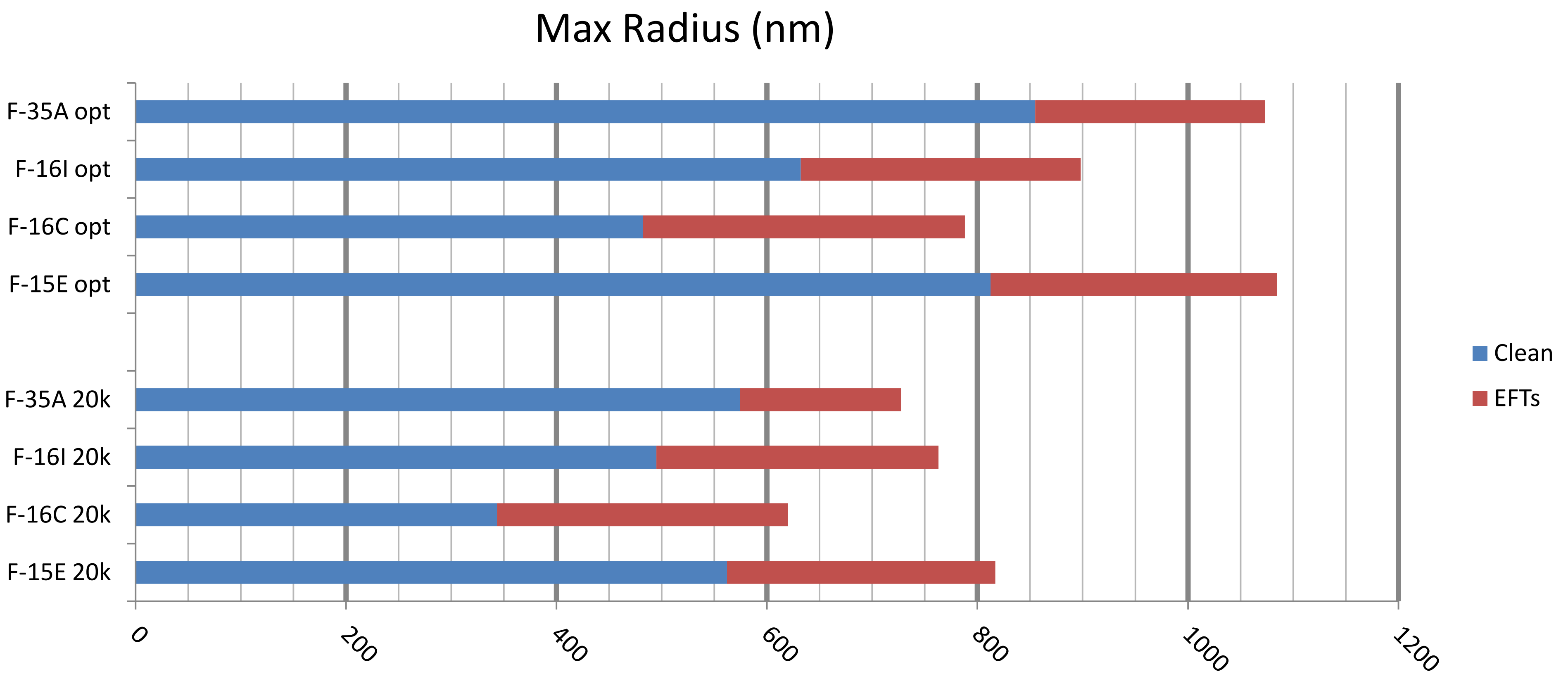
Assumptions:

EFTs are dropped as soon as they are empty

Notes:

The Constrained Flight Plan at 20,000ft shows results similar to the number compared to the KPP, but we can see that no clean strike aircraft is going to significantly exceed that range.

In the Strike role, the F-35 clean has range similar to F-16s with EFTs (sometimes greater still) and comparable to the significantly larger Strike Eagle



Conclusions

- We see that under actual combat conditions the F-35 can climb, run, and turn as well as or better than its stable mates. It does this while having a better ECM/EA suite, full IR targeting and spherical tracking, secure LPI networking, and all aspect X-Band VLO. In short it is more capable than anything that has ever been used in combat before.
- Optimum Profile was done to show how "Max Range" mission data could be gathered as these represent leaving a tanker and returning to a tanker with reserves based on aircraft weight, a true best case scenario.
- Constrained Profile was done to show how mission planners and battlespace managers may not want aircraft going across so many altitudes, and max range at 20kft was at much lower speeds than the 0.8M calculated but the mission planners also can't afford to simply wait around.
- When looking at the F-35s clean range at altitudes above 30kft it is easy to see how the last 75nm in and out could be done at 1.25M and still make a 500nm+ range, which falls in line with the statement "150nm of cruise at 1.25M". I may do a case study on this in the future.