



Quantification of Design Trade-Offs When Comparing Transonic Truss-Braced Wing to Advanced Tube and Wing Aircraft

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National Aeronautics and Space Administration

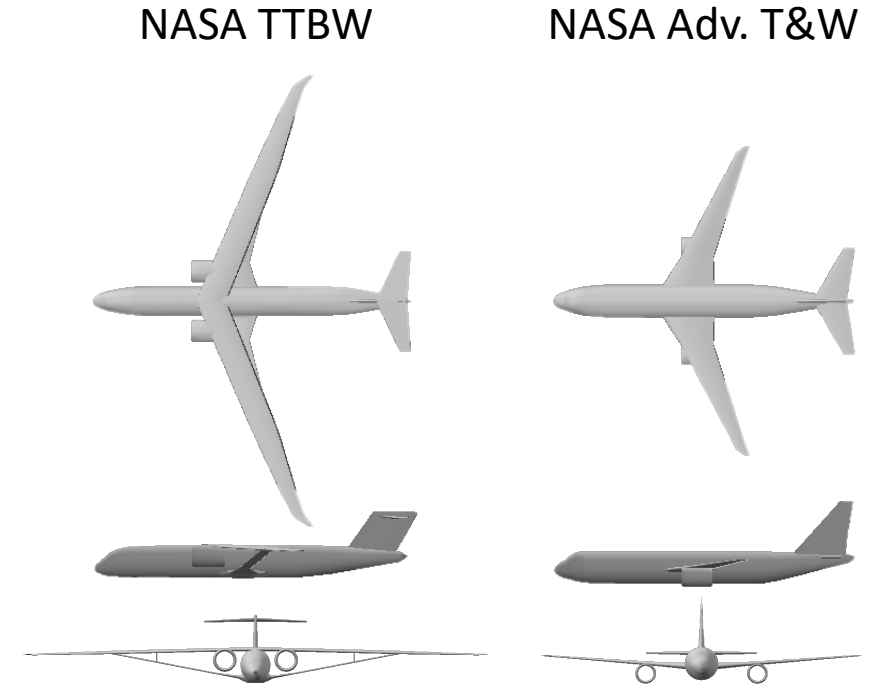
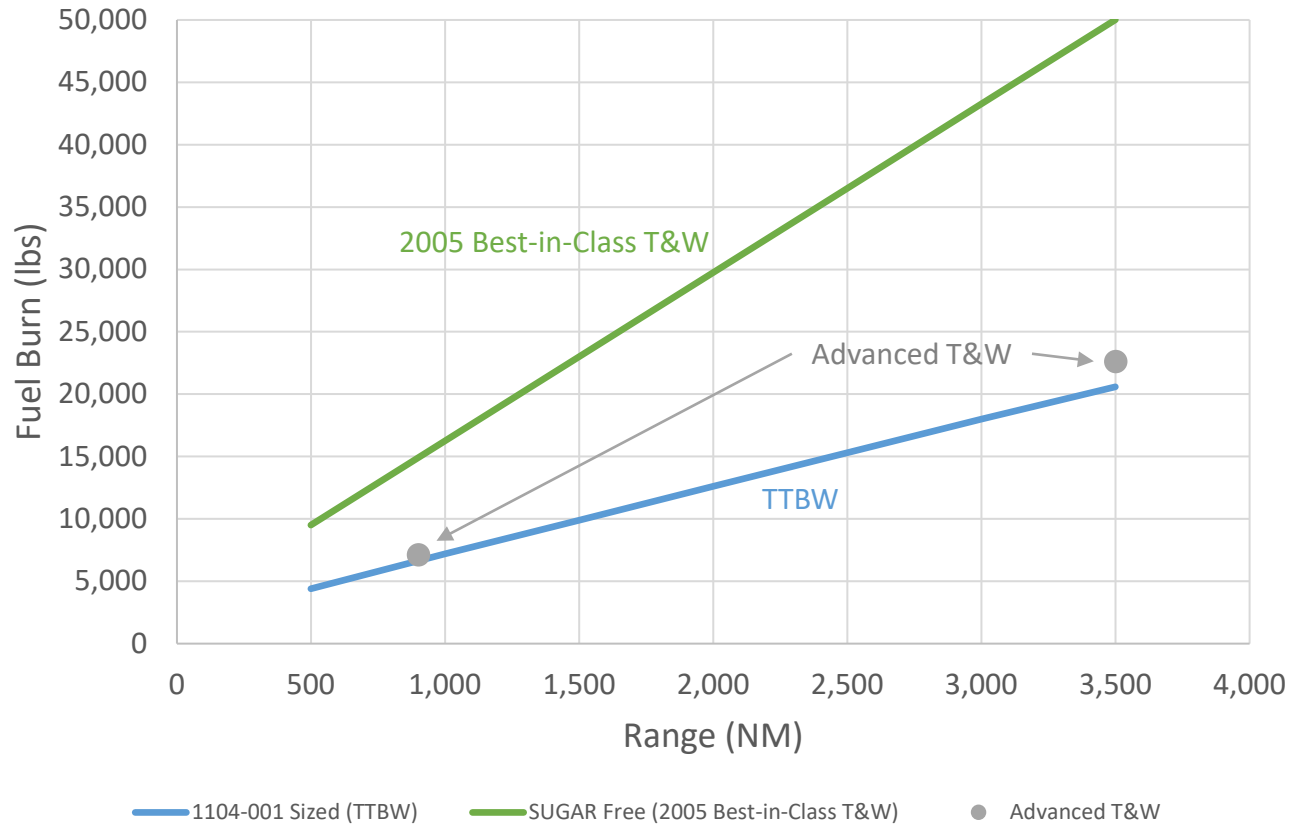
Ames Research Center



Outline

- Introduction
- Methodology
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- Results
- Comparison with Historic Usage
- Conclusion

Boeing TTBW vs. T&W



It is important to determine if the differences in reported fuel savings are due to changes in the governing assumptions and/or due to using different tools or methods.



Methodology – Original Assumptions

	Assumption Set 1	Assumption Set 2	Assumption Set 3
Payload	37,800 lbs • 189 pax – 200 lbs each	30,800 lbs • 154 pax – 200 lbs each	33,750 lbs • 150 pax – 225 lbs each
Advanced T&W AR	11	13	13
Wingspan Limitations	Wing Fold if >118 ft	Wing Fold if >118 ft	Wing Fold if >118 ft
Design Range	3,550 NM	3,500 NM	3,402 NM
Cruise Speed	Design for Mach 0.8 • Flown at Mach 0.8	Design for Mach 0.8 • Flown at Mach 0.775	Design for Mach 0.8 • Flown at Mach 0.8
Fuel Storage	All fuel in wings	Body tanks allowed • Specified wing loading	All fuel in wings
Advanced Technology	2035 Aerodynamic and Structural	2035 Aerodynamic and Structural	2035 Aerodynamic and Structural
Engine Type	LEAP-1B DDTF	2035 DDTF (gFan+)	2035 GTF and DDTF
Engine Cycle	Consistent for all vehicles	Consistent for all vehicles	Optimized for each vehicle • Optimized for best cruise altitude

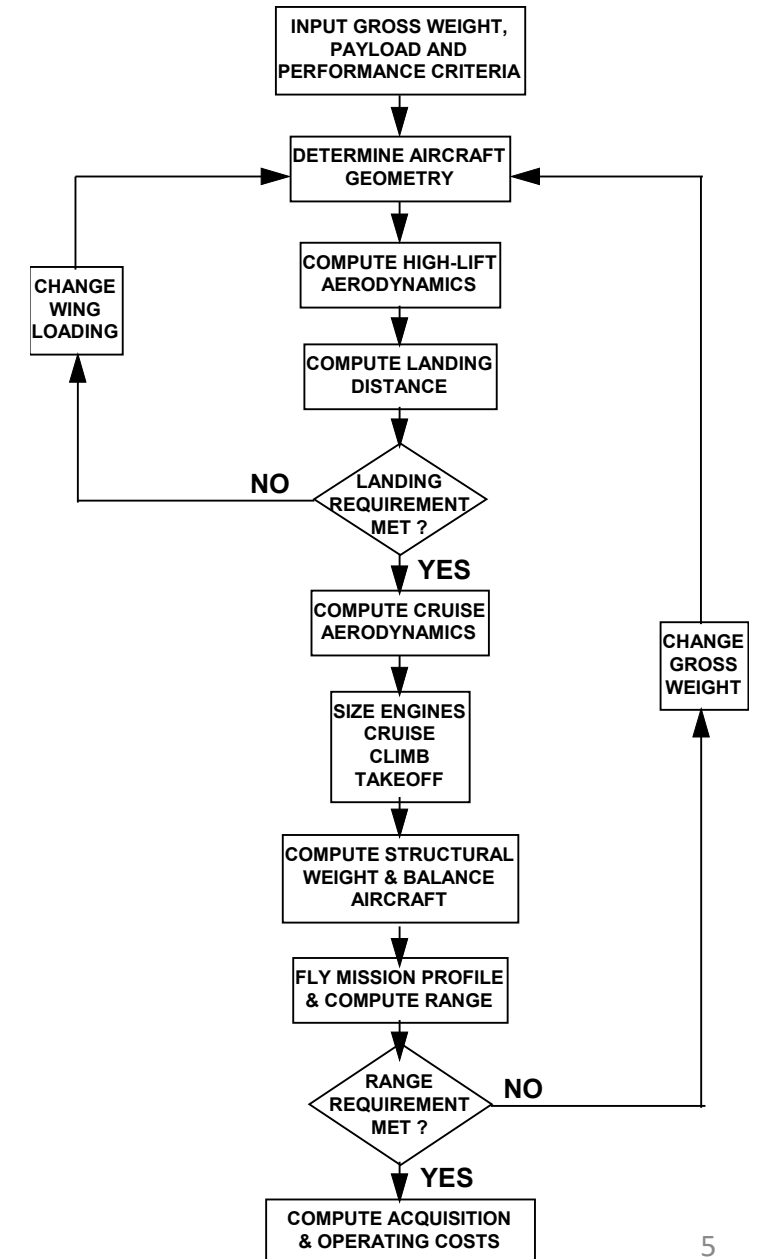


Methodology - GASP

GASP (General Aviation Synthesis Program) is a general aviation vehicle synthesis and design code developed in the 1970's at NASA Ames and further developed and enhanced at Georgia Tech in the 1990's. It is primarily used to perform configuration sizing and performance estimation during the conceptual design phase of aircraft design.

- **Key GASP Capabilities:**

- Aerodynamic characteristics based on gross geometric parameters
- Mission Performance
- Weights based on mass-estimating-relationships
- Vehicle Sizing and Closure
- Off-Design Mission Performance
- Range of propulsion concepts modeled
 - Brayton-cycle turbine engines (Turboshaft & Turbojet/turbofan)
 - Propeller/Rotor Performance





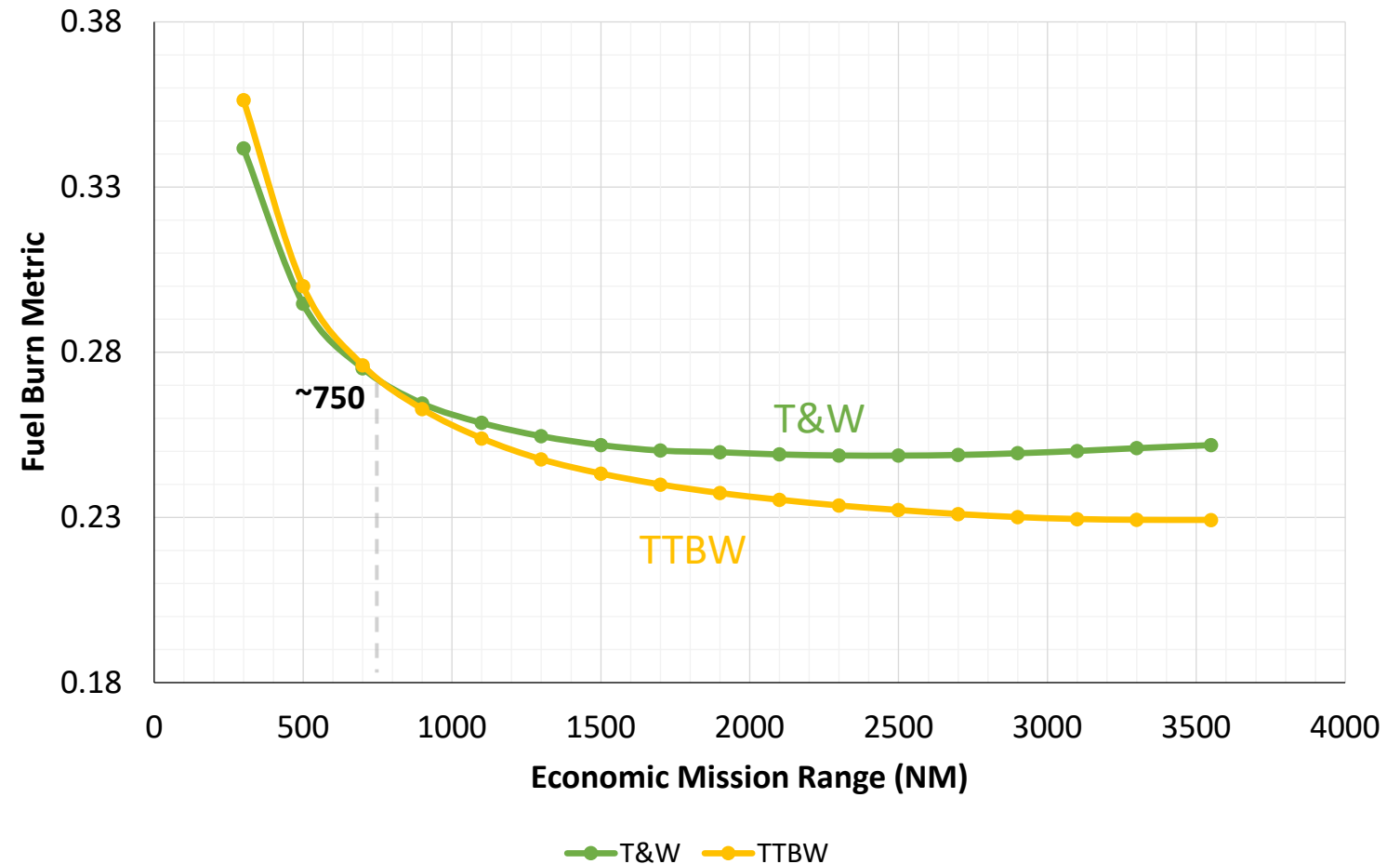
Original Results

$$\text{Fuel Burn Metric} = \frac{\text{Block Fuel/Payload}}{\text{Range}/1000 \text{ nmi}}$$

Assumption Set 1

- **37,800 lbs Payload**
 - (189 pax – 200 lbs)
- **Wing AR 11 for Adv. T&W**
- Wing Fold if >118 ft
- 3,550 NM Design Mission
- Designed for Mach 0.8
 - Flown at Mach 0.8
- All fuel in wings
- 2035 Aerodynamic and Structural Technologies
- **LEAP-1B DDTF**
- Consistent cycle for all vehicles

Assumption Set 1





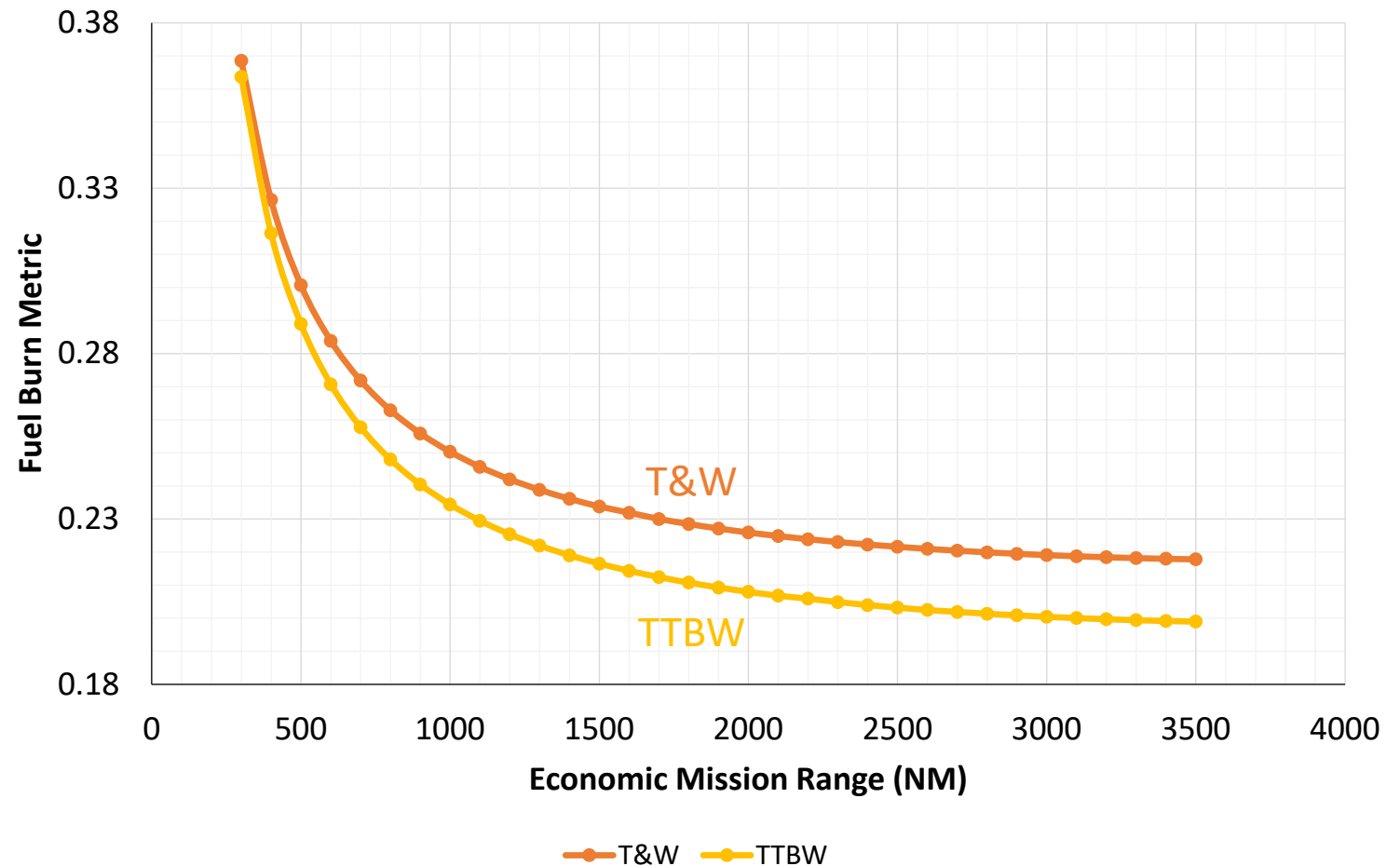
Original Results

$$\text{Fuel Burn Metric} = \frac{\text{Block Fuel/Payload}}{\text{Range}/1000 \text{ nmi}}$$

Assumption Set 2

- 30,800 lbs Payload
 - (154 pax – 200 lbs)
- Wing AR 13 for Adv. T&W
- Wing Fold if >118 ft
- 3,500 NM Design Mission
- **Designed for Mach 0.8**
 - **Flown at Mach 0.775**
- **Body tanks allowed**
 - **specified wing loading**
- 2035 Aerodynamic and Structural Technologies
- 2035 DDTF (gFan+)
- Consistent cycle for all vehicles

Assumption Set 2





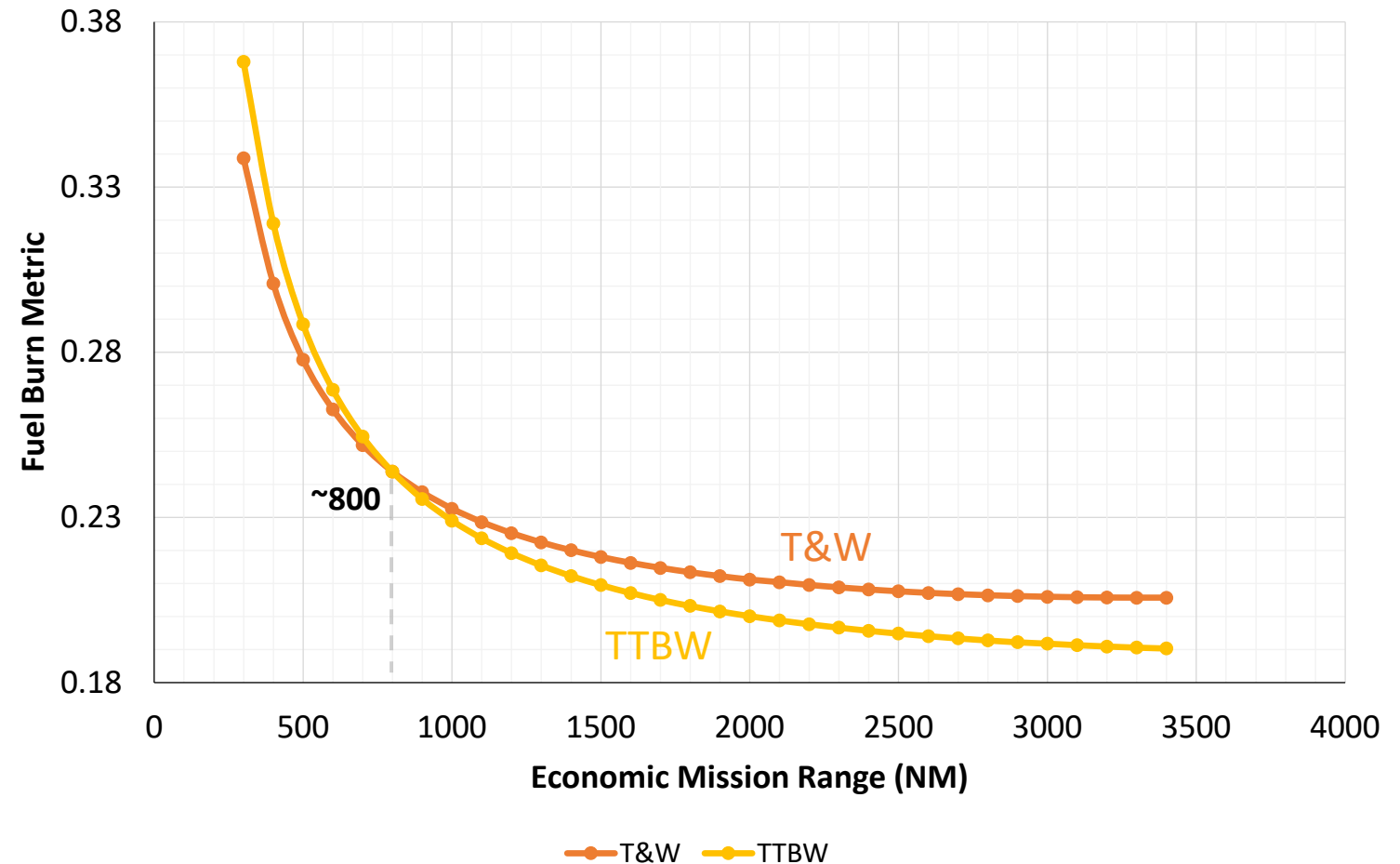
Original Results

$$\text{Fuel Burn Metric} = \frac{\text{Block Fuel/Payload}}{\text{Range}/1000 \text{ nmi}}$$

Assumption Set 3

- 33,750 lbs Payload
 - (150 pax – 225 lbs)
- Wing AR 13 for Adv. T&W
- Wing Fold if >118 ft
- **3,402 NM Design Mission**
- Designed for Mach 0.8
 - Flown at Mach 0.8
- All fuel in wings
- 2035 Aerodynamic and Structural Technologies
- 2035 GTF and DDTF
- **Cycle optimized for each vehicle**
 - **Optimized for best cruise altitude**

Assumption Set 3

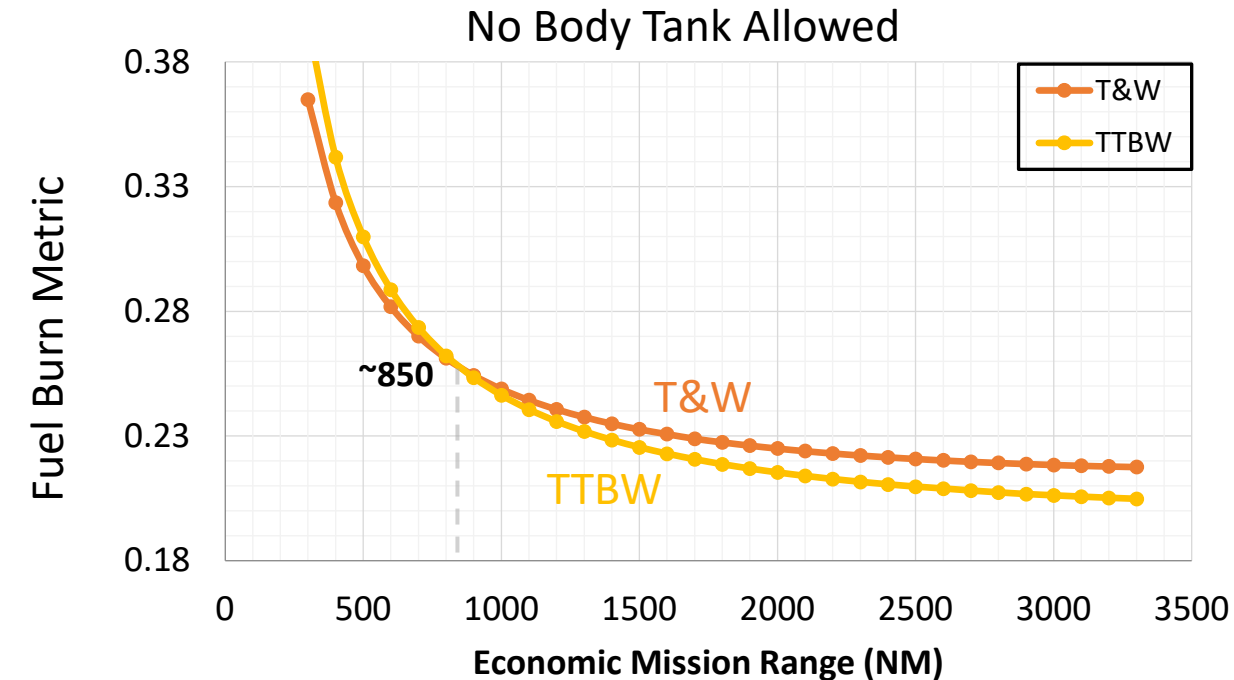




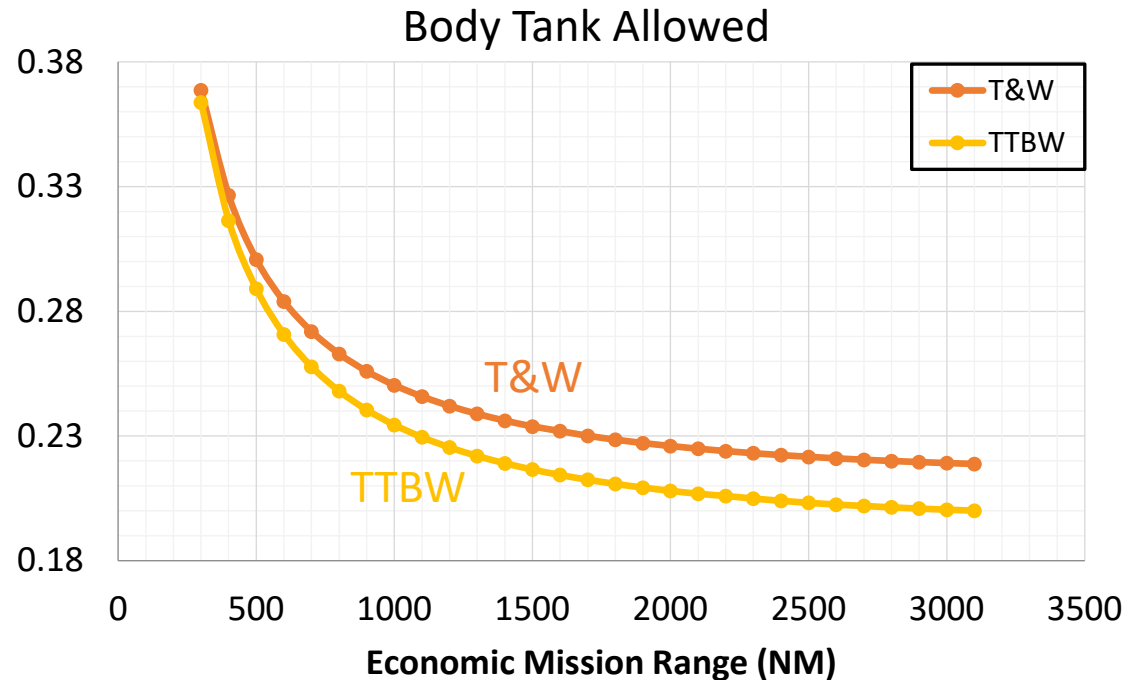
Individual Effects – Body Tanks

$$\text{Fuel Burn Metric} = \frac{\text{Block Fuel/Payload}}{\text{Range}/1000 \text{ nmi}}$$

†Wing loading chosen to match SUGAR



	T&W	TTBW	% Difference
Wing Area (ft ²)	1,299	1,487	14.5%
Wing Loading (lbs/ft ²)	106.3	92.6	-12.9%



T&W	TTBW	% Difference
1,343 (3.39%)	1,197 (-19.5%)	-10.3%
103.7†	107.9†	4.1%

Body tanks: smaller wings → less drag → less required thrust → less fuel → lower weight

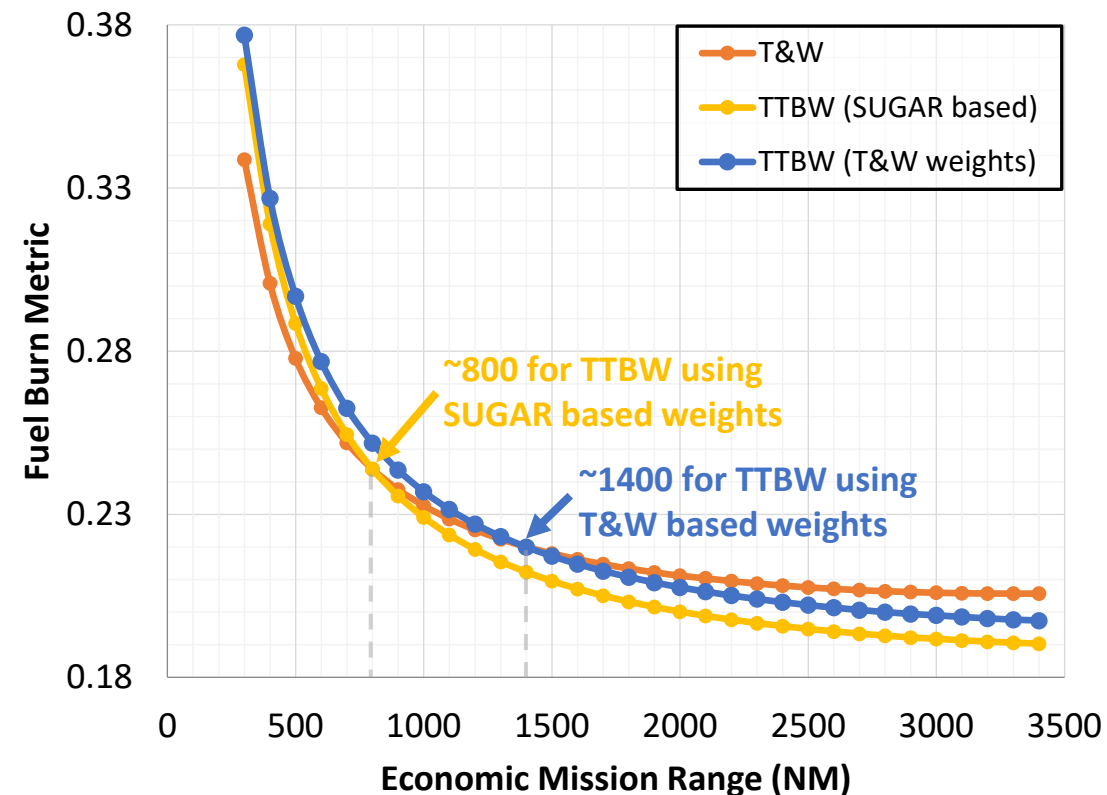
- The thin, high-AR wing of the TTBW can't fit all the fuel without a significant increase in the planform area



Individual Effects – Weight Calibration

$$\text{Fuel Burn Metric} = \frac{\text{Block Fuel/Payload}}{\text{Range}/1000 \text{ nmi}}$$

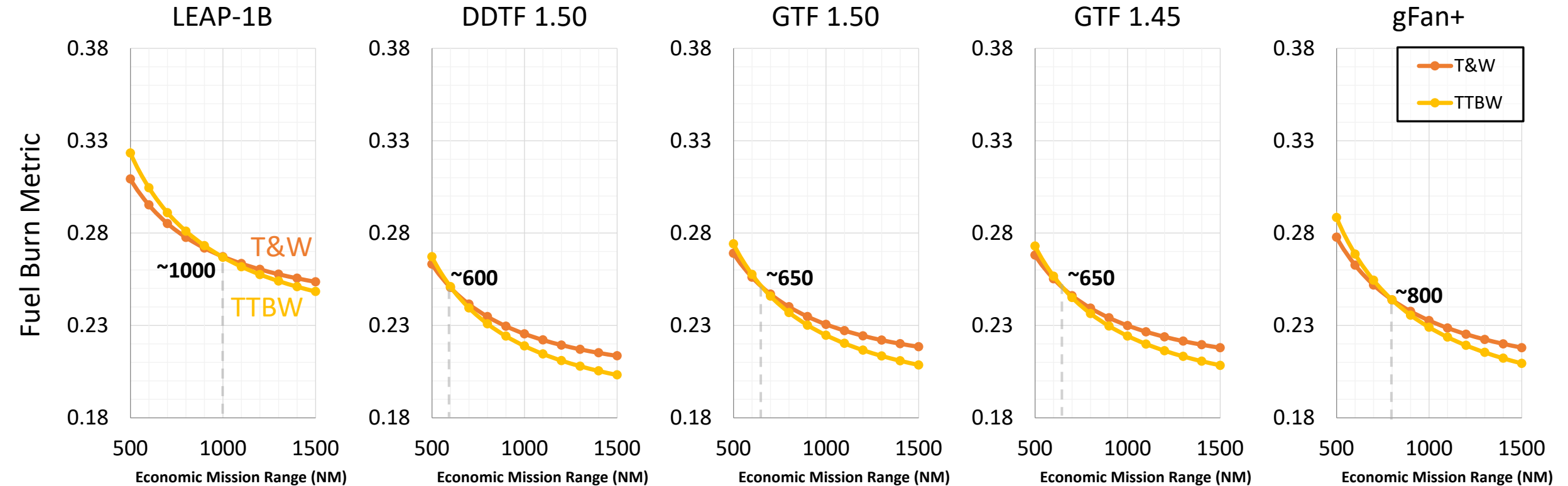
System (lbs)	T&W	TTBW [SUGAR Calibrated]	TTBW [T&W Calibrated]	% Diff [between TTBWs]
Propulsion Group	12,435	16,164	15,392	-4.8%
Primary engines	10,052	13,043	12,780	-2.0%
Engine Installation	1,148	1,489	1,459	-2.0%
Fuel System	1,235	1,632	1,152	-29.4%
Structures Group	40,056	38,914	42,856	10.1%
Wing	12,867	13,045	13,418	2.9%
Strut	--	2,985	3,065	2.7%
Horizontal Tail	2,058	1,247	1,285	3.0%
Vertical Tail	1,408	1,482	1,532	3.4%
Fuselage	15,341	12,249	15,501	26.5%
Landing Gear	5,582	4,725	4,927	4.3%
Engine Section	2,799	3,179	3,127	-1.6%
Flight Controls Group	3,792	2,686	4,423	64.7%
Fixed Equipment	16,027	16,030	16,208	1.1%
Empty Weight	72,311	73,794	78,878	6.9%
Fixed Useful Load	6,108	5,941	5,944	0.1%
Total Fuel Load (3400 NM)	27,387	25,908	26,766	3.3%
Payload	33,750	33,750	33,750	0%
Gross TO Weight	139,555	139,394	145,338	4.3%





Individual Effects – Engine Selection

$$\text{Fuel Burn Metric} = \frac{\text{Block Fuel/Payload}}{\text{Range}/1000 \text{ nmi}}$$



Approximate
Crossover

LEAP-1B	DDTF 1.50	GTF 1.50	GTF 1.45	gFan+
~1000 NM	~600 NM	~650 NM	~650 NM	~800 NM



Individual Effects – Summary

Category	Difference	Effect	Impact on Crossover Point
Body Tanks	Body Tanks Allowed vs. All Fuel in Wings	The thin, high-AR wing of the TTBW can't fit all the fuel without a significant increase in the planform area	Significant (<300 - ~2000 NM)
TTBW Weight Calibration	SUGAR reports vs. T&W	The TTBW empty weight and fuel burn increase when using the T&W calibration	Moderate (~800 - ~1400 NM)
Engines	GRC GTF/DDTF vs. gFan+	The TTBW spends more time climbing and cruises higher, pronouncing differences in engine efficiency during climb and cruise	Moderate (~600 - ~1000 NM)
Flight Mach	Flown at: Mach 0.8 (Design speed) vs. Mach 0.775 (reduced speed)	Without redesigning the aircraft for a lower Mach number, minimal benefits are achieved by flying slower	Minor (~650 - ~700 NM)



Improved Assumptions

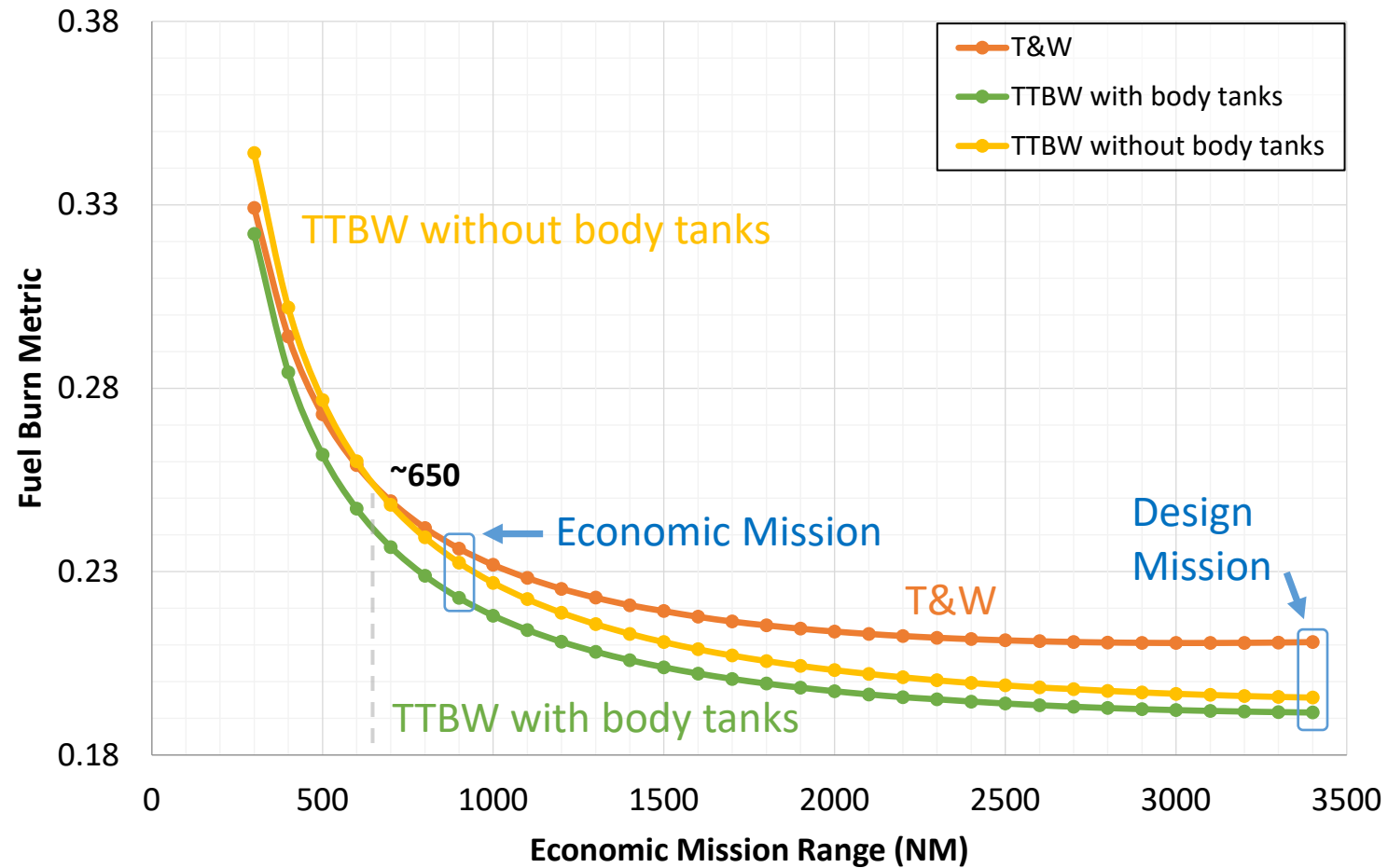
Original Assumption Set 1	Improved Assumptions
37,800 lbs Payload (189 pax – 200 lbs) - Wing AR 11 of Adv. T&W 3,550 NM Design Mission - Design Mach 0.8, Flown at Mach 0.8 2035 Aero-Struct Technology - LEAP-1B Direct Drive Turbofan - Consistent cycle for all vehicles - All fuel in wings	33,750 lbs Payload (150 pax – 225 lbs) - Wing AR 13 for Adv. T&W 3,400 NM Design Mission - Design Mach 0.8, Flown at Mach 0.8 2035 Aero-Struct Technology - Advanced DDTF (FPR 1.50) - T&W based weight calibration - Separate designs for all fuel in wings and some fuel in body tanks

	T&W	TTBW (w/o Body Tanks)	TTBW (w/ Body Tanks)
GTOW (lbs)	140,073	139,853	132,843
Empty Weight (lbs)	72,435	73,863	67,586
Wingspan (ft)	128.7	170.7	155.2
Wing Area (ft ²)	1,317.7	1,489.6	1,231.2
Aspect Ratio	13	19.57	19.57
Cruise Altitude (ft)	40,500	44,750	42,750
Start of Climb L/D	20.9	23.6	22.8
Engine SLS Thrust (lbs)	18,525	23,277	20,810
3400 NM Fuel Burn	24,201	22,384 (-7.51%)	21,929 (-9.39%)
900 NM Fuel Burn	7,204	7,085 (-1.65%)	6,793 (-5.71%)



Improved Assumptions

$$\text{Fuel Burn Metric} = \frac{\text{Block Fuel/Payload}}{\text{Range}/1000 \text{ nmi}}$$

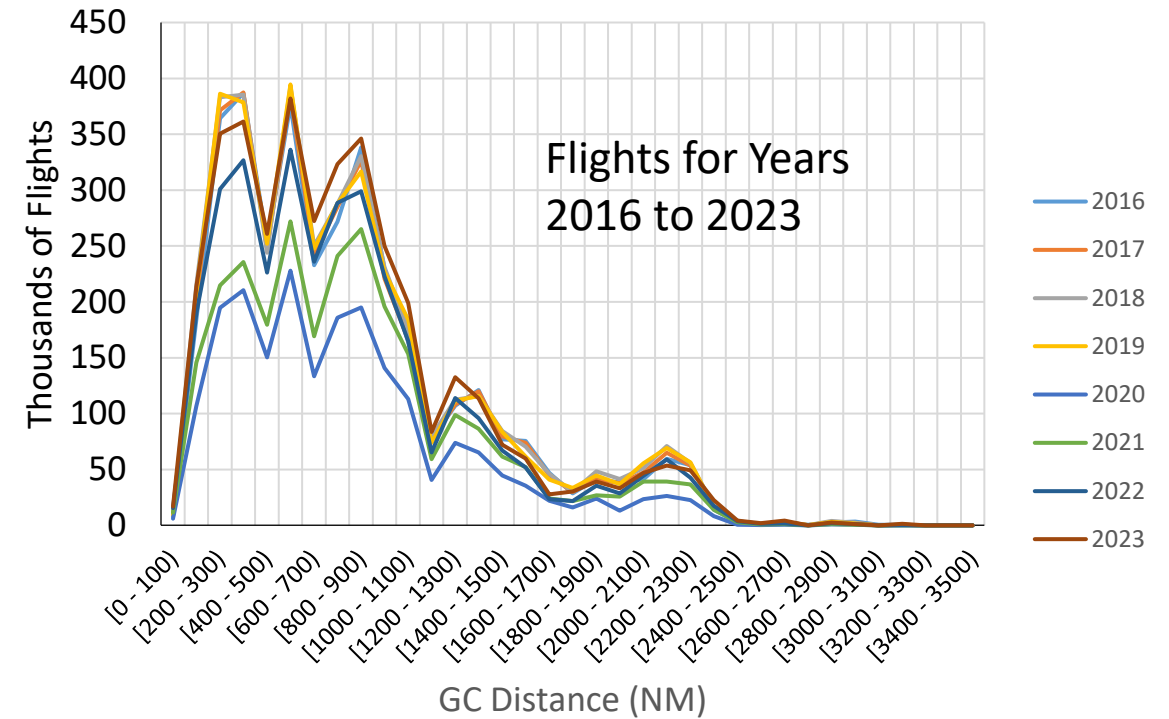
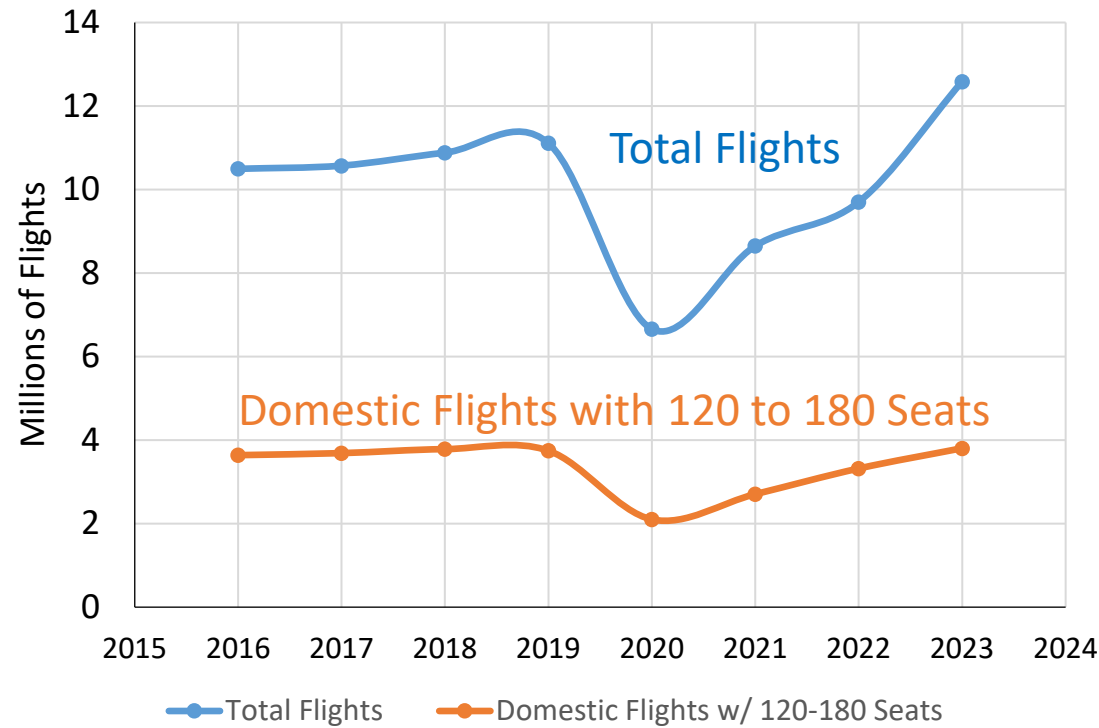




Historic Operations

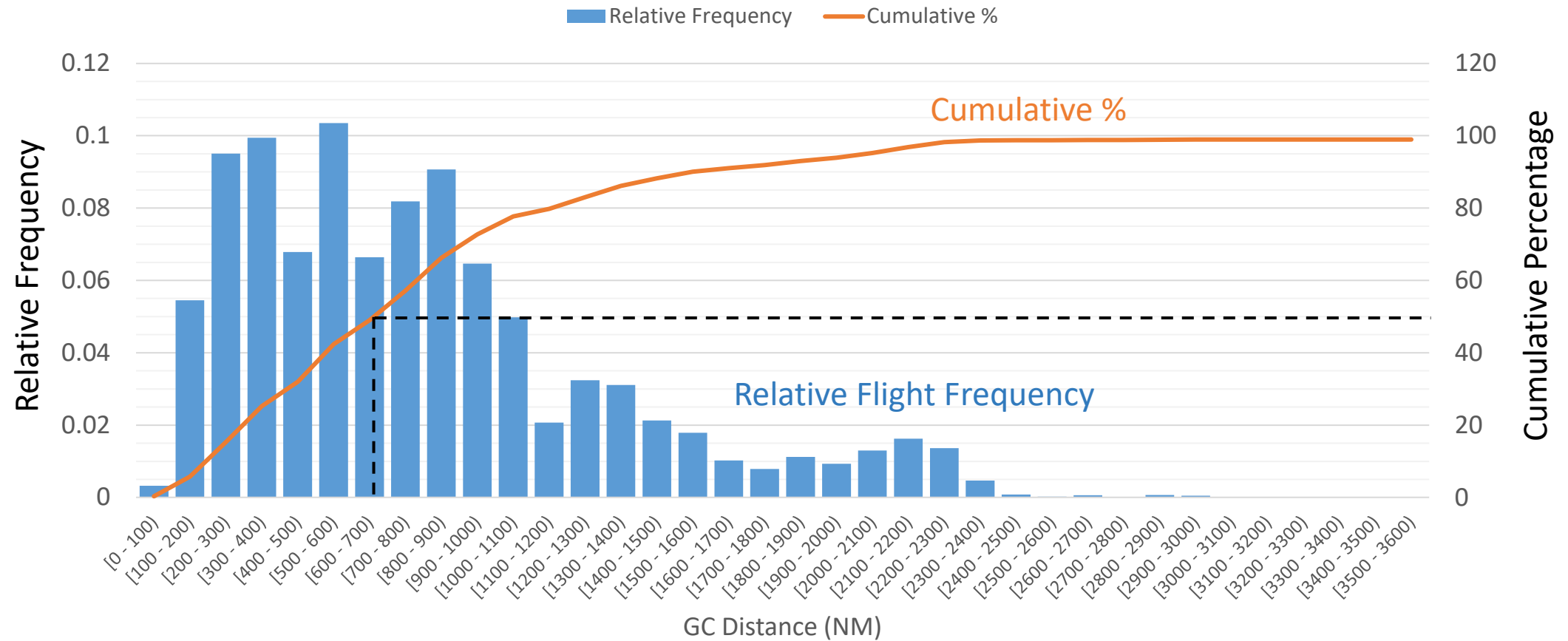
BTS Data:

Aircraft Name	Departure City	Destination City	GC Distance (mi)	Departures Performed	Payload (lbs)	Seats	Pax	Ave Seats	Ave Pax
A319	Oakland, California, USA	Bellingham, Washington, USA	764	14	789600	2184	1934	156	138.1
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮





Historic Operations



	Average Fuel Burn (300-3500 NM)	
Advanced T&W	5845.3 lbs	
TTBW (w/o Body Tanks)	5750.5 lbs	1.62%
TTBW (w/ Body Tanks)	5509.9 lbs	4.19%



Conclusion

- When making the same assumptions as the other groups, we get reasonably close results that result in the same conclusions.
- Certain assumptions and requirements that were originally inconsistent between groups have a significant impact on the overall performance of the vehicles, and as a result, the crossover point.
 - Allowing or prohibiting body tanks had the most significant impact
 - Accurately predicting the weight of the TTBW structure has a moderate impact
- Even if the TTBW doesn't outperform the T&W at all ranges, the significant savings the TTBW offers at long ranges results in an overall benefit over the advanced T&W