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Fuel-Burn Impact of Re-Designing Future Aircraft with Changes in Mission Specifications

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Over the past few years, pressure to reduce the overall fuel consumption of the commercial aircraft fleet has been growing steadily. Expenses related to fuel are now one of the largest contributors to an airline's direct operating cost. In addition, harmful emissions derived from the engine combustion process (CO_2, NO_x, and others) must be significantly reduced in order to meet future targets that the industry has set for itself. The fuel burn impact of varying design mission specifications (payload, range, cruise Mach number, and allowable span) of tube and wing aircraft is studied in this paper. Representative aircraft from all groups (Regional Jet - CRJ900, Single Aisle- B737-800, Small Twin Aisle- B767-300ER, Large Twin Aisle- B777-200ER, and Large Aircraft - B747-400) are chosen and redesigned for variations in the design cruise Mach number, wing span and R1 range. In addition, the effects of improvements in aerodynamic, structural and propulsion technology expected over the next 20 years are taken into account in the context of technology scenarios for which the baseline aircraft are redesigned. The effectiveness of mission specification changes in reducing the fuel burn of these technologically advanced aircraft is also observed. Results from aircraft redesigns indicate that variations in design mission specifications can result in aircraft with improved fuel burn characteristics (up to a 24 percent reduction). Results also indicate that even for aircraft at higher technology levels, mission specification changes can still contribute to significant improvement in aircraft performance.

Nomenclature

ATK	Available tonne-kilometer
AR	Aspect ratio
C_L	Coefficient of lift
CAEP	Committee on Environmental Protection
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
GHG	Greenhouse gas
ICAO	International Civil Aviation Organization
kg/ATK	Fuel burn metric, kilograms of fuel burned per available tonne-kilometer
LFL	Landing field length
LTA	Large Twin Aisle
LTTG	Long-term technology goals
$MTOW$	Maximum take-off weight
$MZFW$	Maximum zero fuel weight
NAS	National Airspace System
OEW	Operating empty weight
R1 Range	The maximum range that can be flown by the aircraft with its full design payload
RJ	Regional Jet

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SA	Single aisle aircraft
SFC	Engine specific fuel consumption
S_{ref}	Reference area
STA	Small twin aisle aircraft
$TOFL$	Take-off field length
VLA	Very Large Aircraft

I. Introduction

With soaring fuel prices, environmental concerns and stringent regulations regarding emissions, reduction in fuel burn and emissions has become a major goal for the airline industry. Technology advances (aerodynamics, propulsion, and structures) have traditionally been the largest contributors to fuel burn reduction achieved by the current fleet. Concepts like boundary layer ingesting inlets, laminar flow wings, ultra high bypass engines, open rotors, electric propulsion and unconventional configurations like the blended wing body and the D8[2] are examples of technological advances being actively researched by academia and industry with the goal of fuel burn reduction. However, as a result of sharply increasing air traffic at a global level, these technological advancements might not be enough to meet self-imposed, stringent targets regarding emissions(like carbon neutral growth by 2020). Moreover, historical trends are pointing to a slowing down of the rate of technological progress compared to that achieved over the past 40 years. Given the added difficulty of achieving further reductions in fuel burn through technology insertion, we ask ourselves the question of whether other sources of fuel burn improvements can be found. It is well known that altering the design payload/range characteristics of an aircraft can result in substantial reductions in fuel burn. Thus, the fuel burn impact of decreases in cruise Mach number, changes to the R1 range and removing restrictions on the maximum allowable span of an aircraft are explored in this paper.

The ICAO CAEP study by a panel of Independent Experts in 2009[9] and the work by Economon et al.[1] showed that making changes to the design mission specifications of aircraft was an approach with considerable promise. To look at this concept in detail, the FAA initiated a study in 2011 with the objective of exploring the system level effect of design mission specification changes on the fuel burn of existing and futuristic(aircraft at improved technology levels) aircraft. The work presented here was done as part of that effort and looks at the fuel burn impact of making mission specification changes for aircraft of various classes.

II. Methodology

A. Mission Specification Changes

The design mission specifications to be studied are cruise Mach number, wing span and R1 Range. These mission specifications were chosen based on earlier studies ,[1] ,[9] [8] and initial work which indicated that that making changes to cruise Mach number, wing span or R1 range had a significant effect on the mission fuel burn metric. The cruise Mach number is varied from the design cruise Mach number of the baseline aircraft to Mach 0.65 at intervals of Mach 0.1. The R1 range is varied from 30 % to 140 % of the baseline aircraft's R1 range and wing span is varied from 70 % to 180 % of the baseline aircraft's wing span.

B. Technology Improvement Prediction

Next we define the technological improvements to be modeled for the improved technology aircraft.Technology advancements are characterised in the form of technology improvements achievable by 2024 and 2034. For each time frame the technology levels are sub-classified into evolutionary(TS1), stretch (TS2) and aggressive(TS3) based on the predicted rate of improvement deemed possible. Evolutionary implies a continuation of current improvement trends (TS1), Stretch requires an increased pressure leading to significant additional technology adoption (TS2) and an Aggressive scenario indicates further increased pressure leading to radical technology adoption (TS3).

Four technology levels are studied here TS1,TS2 and TS3 for 2024 and TS3 for 2034. The overall technological improvement predictions for each level are summarised in the form of technology improvement factors that indicate improvements in the aerodynamic, structural and propulsion performance of the aircraft due to technological advancements like increased laminar flow, use of composites, introduction of open rotors. The baseline aircraft from all the classes are then redesigned with these technological improvements taken into account. This gives us the predicted reduction in fuel burn for aircraft from different classes due to technological improvements alone at different technology levels. An example of the the technology factors used is shown in Fig. 1. The table shows the viscous and inviscid aerodynamic improvements, propulsion performance improvement and structural weight improvements at the various technology levels for single aisle and twin aisle aircraft. The values labelled LTTG are the improvements predicted for these aircraft by the ICAO CAEP study by a panel of Independent Experts in 2009.[9] Detailed information about the technology scenarios will be stated in the Partner Project 43 final report.

	Single Aisle			
	2024 - Evolutionary	2024 - Stretch	2024 - Aggressive	
		2034 - Evolutionary	2034 - Stretch	2034 - Aggressive
Viscous Aerodynamic Efficiency				
Nacelle		3.2%	3.5%	3.5%
Wings		2.0%	6.9%	9.8%
Empennage & Fuselage		2.0%	4.0%	4.0%
LTTG Values (aircraft level)	2%	4%	7%	9%
Non-viscous Aerodynamic Efficiency				
Wings (in % improvement in drag)		10.1%	11.4%	13.2%
Reduction of loads (active smart wings) - in % fuelburn		1.5%	2.0%	3.0%
LTTG Values (aircraft level)	2%	4%	6%	7%
Engine				
Configuration		GTF (PW1000G)	Improved GTF	Open Rotor
%SFC Improvement		17%	22%	30%
%SFC Improvement modeled by Tecolote		17.5%	19.6%	TBD
LTTG Values (Propulsion)	13%	14%	15%	28* %
LTTG Values (Thermodynamics)	3%	4%	5%	3* %
Structures (aircraft level)		12%	14%	22%
LTTG Values (aircraft level)	10%	15%	20%	20* %

Figure 1. Revised Technology Scenarios.

C. Baseline Aircraft Selection

The first step towards a system level understanding of the effect of mission specification changes and technological improvements on fuel burn is to look at their effect on a wide range of aircaft with different payload range characteristics. With this goal in mind, aircraft used in commercial operations are divided into 5 classes based on the ICAO classification (payload range characteristics), the Regional Jet, Single Aisle Aircraft, Small Twin Aisle aircraft, Large Twin Aisle and Very Large Aircraft . A representative aircraft is selected from each of these classes as a baseline and a conceptual level modelling and performance analysis is conducted for each baseline in the conceptual design framework chosen for this study. These representative aircraft are shown in Fig. 2.

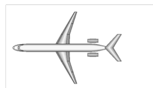
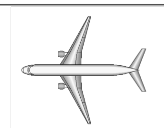
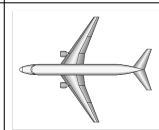
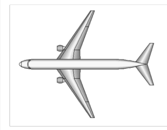
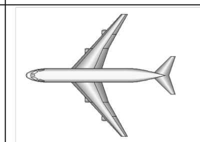
Aircraft Class	Regional Jet (RJ)	Single Aisle Aircraft (SA)	Small Twin Aisle Aircraft (STA)	Large Twin Aisle Aircraft (LTA)	Very Large Aircraft
Representative Aircraft	CRJ900	B737-800	B767-300ER	B777-200ER	B747-400
Pass Model Representation					

Figure 2. Baseline aircraft chosen for redesign and analysis.

The geometry, weight statements and performance estimates (fuel burn, thrust, Cl, Cd, etc) are compared with publically available data/literature and with other conceptual design tools (EDS, TASOPT) to ensure that the modelling is accurate. Then these baseline aircraft are then redesigned for changes in the design mission specifications and technological improvements. Finally fuel burn characteristics of these redesigned derivatives are studied.

D. Design Framework

The design framework (Fig. 3) consists of a set of conceptual design tools coupled with an optimizer. The framework enables redesign of an aircraft using the design tools for an objective which could be MTOW, direct operating cost, mission fuel burn or any other metric of fuel burn.

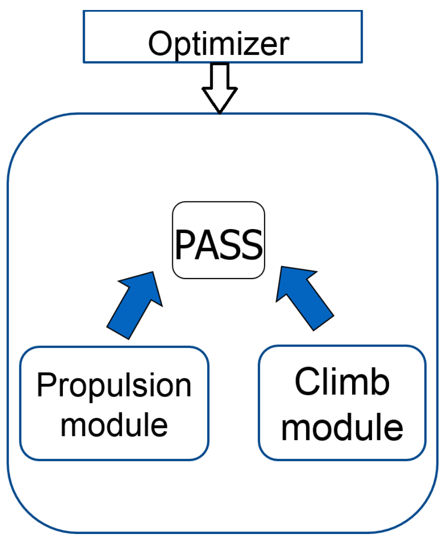


Figure 3. Conceptual design framework.

1. *Design Environment*

For conceptual analysis, Program for Aircraft Synthesis Studies (PASS), a conceptual design code developed by the Aerospace Design Group[14] at Stanford University, is used. PASS is capable of a conceptual level modelling of tube and wing aircraft, by taking in the aircraft geometry, design mission specifications (cruise Mach number, payload, passengers,etc) and computing the aircraft performance for the R1/design mission.

PASS contains simple aerodynamic, structual, propulsion and stability modules coupled together enabling the design of a conventional tube and wing aircraft. This conceptual level modeling is computationally inexpensive and suited for large design space explorations.To study advanced technology aircraft, PASS also has a set of technology modelling factors which can be used to model improvements in the aerodynamics, structures or the propulsion system of the aircraft. These factors are used to study technology improvements for conventional tube and wing aircraft.

For the present study, it is observed that the ability to effectively redesign the propulsion system and model its off-design performance is important for the Mach reduction case. For this purpose, PASS is coupled with an in-house propulsion design and analysis code in order to improve the performance estimation.The propulsion analysis module utilises a 1D engine analysis for the design and sizing of the turbofan engines. This allows engine geometry and parameters like component pressure ratios, bypass ratio, polytropic effeciencies to be incorporated in the design process. In the estimation of off-design performance, fan /compressor speed matching is performed using compressor maps. As detailed compressor maps for existing aircraft engines are hard to find, existing compressor map data is regressed using surrogate models built with a Gaussian process regression toolbox[19] as shown in Fig 5.

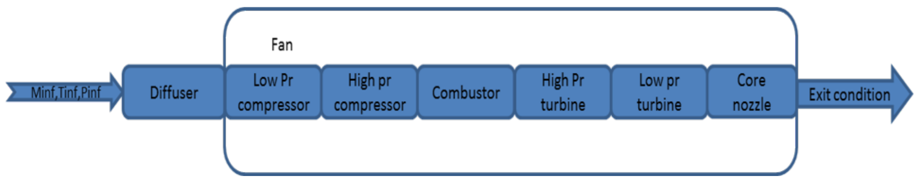


Figure 4. Propulsion analysis module.

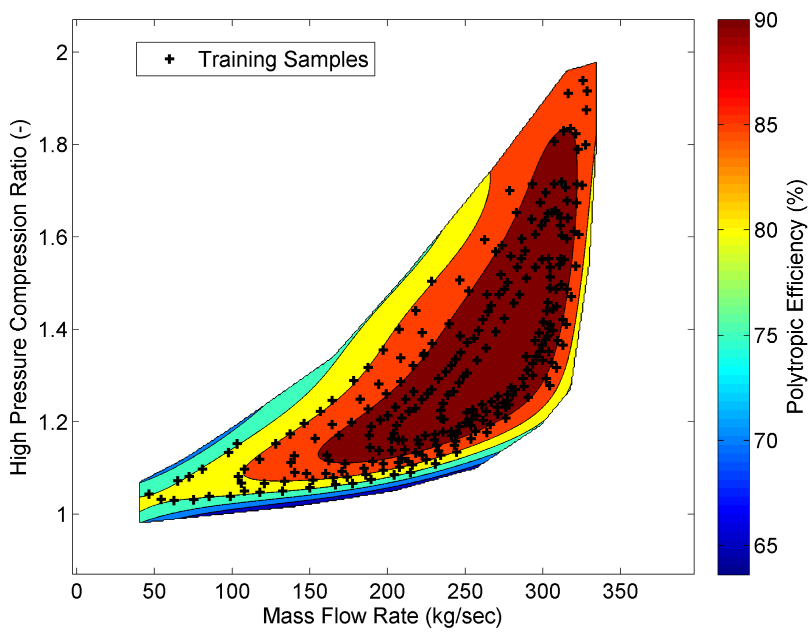


Figure 5. Compressor map regressed as a response surface.

Also, to study the effect of redesigning aircraft for smaller R1 ranges, effectively modeling the climb segment is important. This is because for small missions climb is a major contributor to the mission fuel burn. So, the design framework also includes an in-house climb model that can analyze a climb phase composed of an arbitrary number of segments, which results in a better estimation of its fuel burn (Fig. ??).

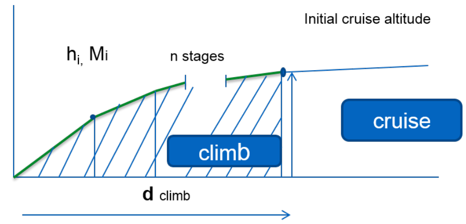


Figure 6. Climb model.

2. Redesign/Optimization Problem

The redesign of the aircraft for a chosen mission specification change is performed in the form of an optimization problem. The design tools described above are coupled with a gradient-based optimizer. Optimization is important to ensure that the improvements observed from the redesigned aircraft form the upper bound of the improvement possible with the mission specification/technology changes applied to the baseline aircraft. The fuel burn improvements are computed in terms of kilograms of fuel burnt per allowed tonne of payload per unit range in km(kg/ATK). This is consistent with the existing results[19] and removes the dependency of the results on the mission payload and range. This makes comparison of the fuel burn properites of the optimized aircraft with the baseline aircraft easy. Optimization is performed using matlab's fmincon optimizer using a gradient based approach.

Objective Function: The fuel burn metric kg/ATK is used as the objective function for the optimization process.

Design Variables: Redesigning the aircraft for different cruise Mach, span or R1 range or a combination of the same for reduced fuel burn metric results in changes to the geometry and weights of the various aircraft components like the main wing, horizontal and vertical tails, and the engine. It also requires modification to mission related parameters like landing and take off mach numbers, the cruise altitudes, climb profiles. Thus, the design variables are the geometric parameters of the wing and the horizontal and vertical stabilizers, the propulsion system parameters and the mission parameters stated above. The Fig. 7 contains a list of the design variables used for this study.

Max takeoff weight	Wing reference area (sref)	Wing aspect ratio	Sweeps(wing, horizontal and vertical tails)
Wing thickness to chord ratio	Wing taper	Wing position	Area ratios (wing, horizontal and vertical tails)
MZFW/MTOW	Flap and slat deflections at takeoff and landing		Engine parameters: • Turbine Inlet Temperature, • Fan, Low And High Pressure Compressor Pressure Ratios, • Bypass Ratio
Take off and landing Mach numbers	Cruise Mach number	Initial and final cruise altitude	

Figure 7. Design variables used in aircraft redesign and optimization.

Constraints: A vital part of the optimization process is the selection of constraints in order to ensure feasible and realistic designs. This is a serious concern especially with conceptual level modeling as optimizers tend to converge to efficient but infeasible designs if the optimization problem is not constrained carefully. Therefore realistic thrust-to-drag ratios, lift-to-drag ratios, stability margins and Cl margins are enforced. It is also important to ensure that the redesigned aircraft lies within the same technology level and performs the same mission as the baseline aircraft of that class. For example a single aisle baseline technology aircraft when redesigned should not result in a twin aisle TS2-2024 aircraft. An example of a constraint to avoid this issue invovles constraining engine optimization with limits on engine weight and nacelle drag increment to protect against very high bypass ratios or exceedingly high pressure ratios. The redesigned aircraft should also meet the FAA regulations (FAR) to be airworthy. Constraints such as meeting minimum climb gradients during takeoff, speed requirements during climb below 10000 ft, takeoff and landing field lengths are enforced for this purpose. The Fig. 8 contains a list of the constraints used for this study.

Cruise range	Take off and landing field lengths	Stability margin	2nd segment Climb gradient
landing gear position	Drag to thrust ratios	Cl(coefficient of lift) margins at different segments of the mission	Wing span

Figure 8. Constraints used in aircraft redesign and optimization.

Given the objective function, design variables, and constraints specified above, design optimization runs are performed on the baseline and improved technology aircraft. The results of these runs are described below.

III. Results

Mission specification changes to baseline aircraft lead to significant improvements in the fuel burn metric for aircraft from all the classes. First, we will look at the effect of changing each mission specification and then at the effect of combining mission specification changes.

A. Cruise Mach Reduction

Cruise Mach number reduction is observed to be the most effective mission specification in terms of fuel burn reduction. Reduction of cruise Mach number permits unsweeping of the wings. It also contributes to increased t/c ratios for the main wing both of which result in reduced structural weight. This allows for smaller/lighter wings resulting in increased aspect ratios for the existing span resulting in lower induced and parasite drag along with compressibility drag reductions due to lower mach number flight. Thus the thrust requirement during cruise is significantly reduced. Furthermore redesigning propulsion systems for lower mach numbers results in sfc reductions of close to 10-15% especially for the aircraft flying at Mach 0.84, 0.85 (B747-400,B777-200ER) reducing the fuel burnt per unit thrust. The coupling of these effects results in significant reductions in the fuel burn metric for a mission similar to the baseline with the same R1 range and payload.

The effect of mission specification changes on the design parameters that were described above are evident from figure 14. The variation in fuel burn with cruise Mach number is shown in Figs 9,10,11,12,13.

Interestingly for higher technology aircraft too, the relative effect of mission specification changes is still fairly strong. For the B737-800, for the TS3-2034 technology scenario, an 8% reduction in fuel burn metric is observed for an aircraft flying at Mach 0.68 compared to Mach 0.8. The relative effect of cruise Mach number reduction on fuel burn does not change much with the tchnology scenario. Similarly for the B777-200ER at TS3-2030, the relative reduction of fuel burn metric due to cruise Mach number reduction was 13% compared to Mach 0.84. Thus having low Mach variants for the improved technology aircraft can contribute to reduction in fuel burn and emissions as well. The trend for the fuel burn metric with cruise Mach number is shown below.

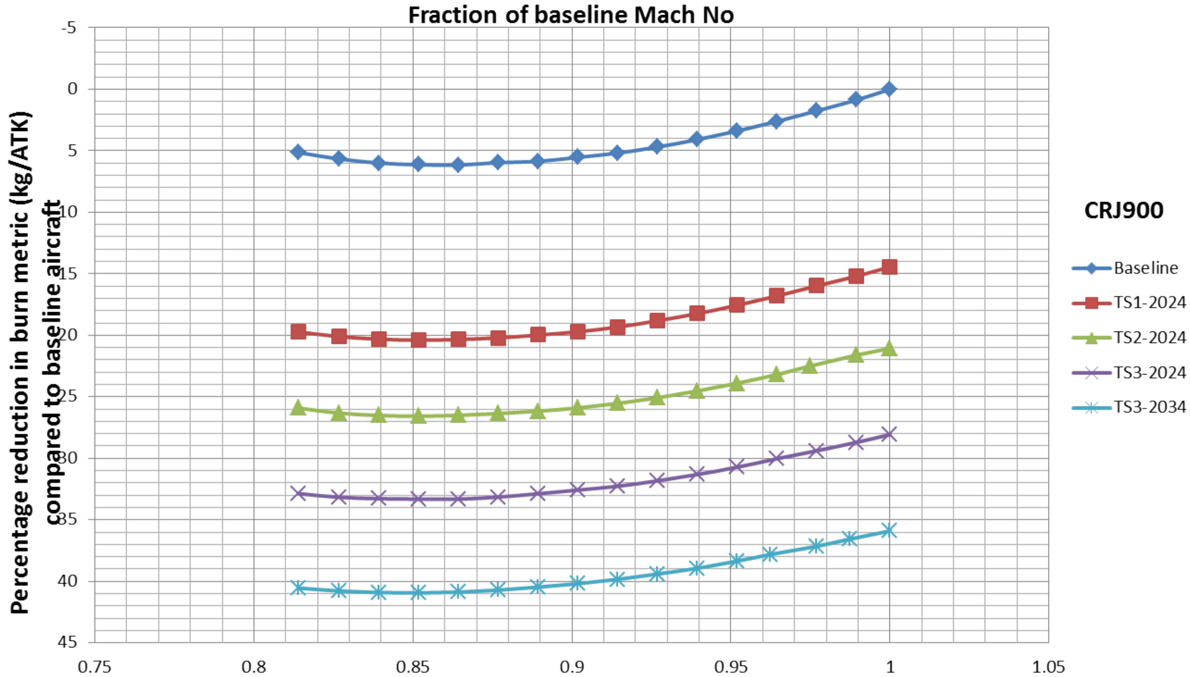


Figure 9. CRJ900 Mission specification variation effect on fuel burn.

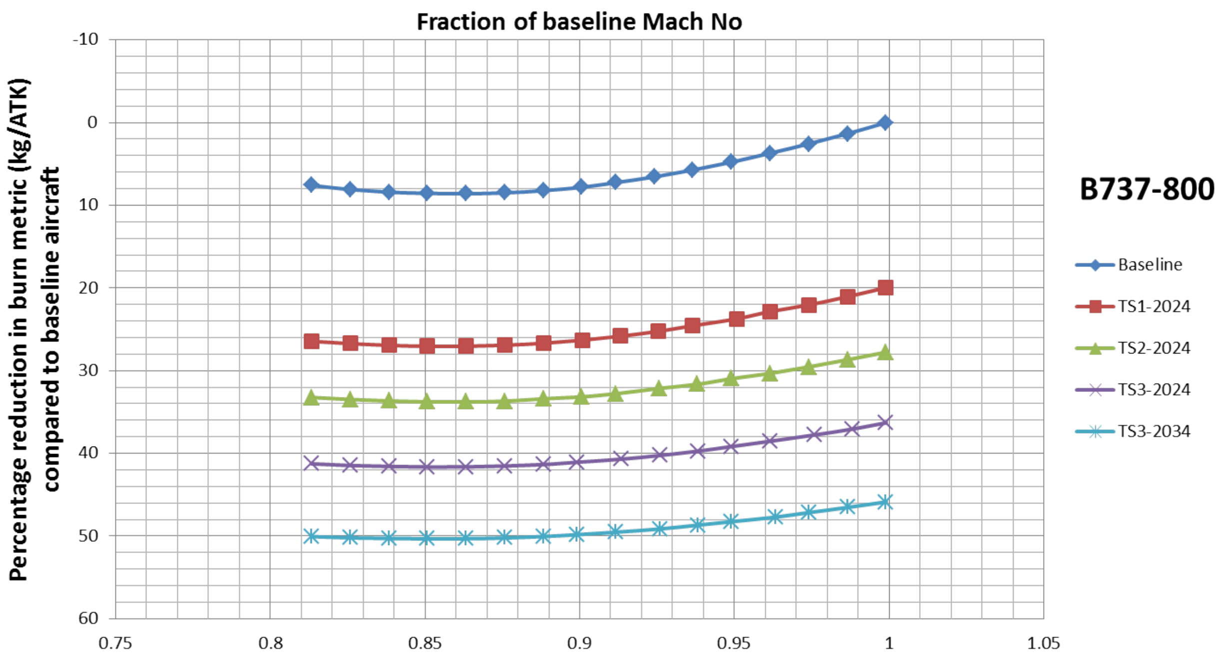


Figure 10. B737-800 Mission specification variation effect on fuel burn.

The plot for the B737-800 clearly shows that a 15 % reduction in cruise Mach number results in close to a 10% reduction in fuel burn metric for the aircraft. For higher technology levels the optimum seems to move towards lower cruise Mach numbers due to the improvements from technology as well.

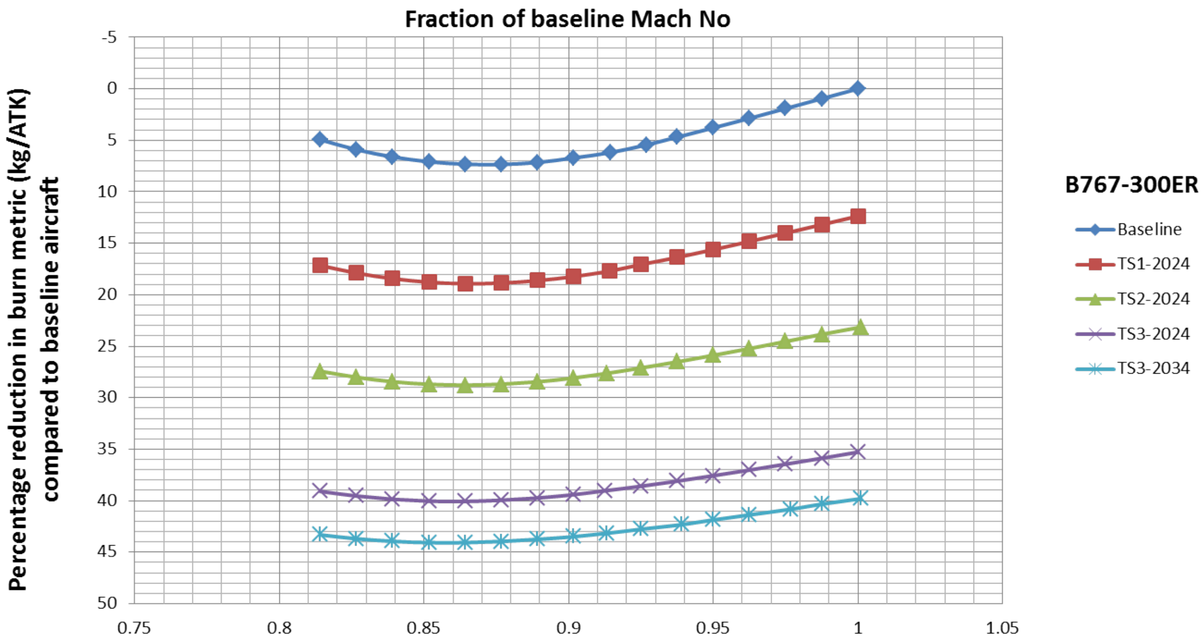


Figure 11. B767-300ER Mission specification variation effect on fuel burn.

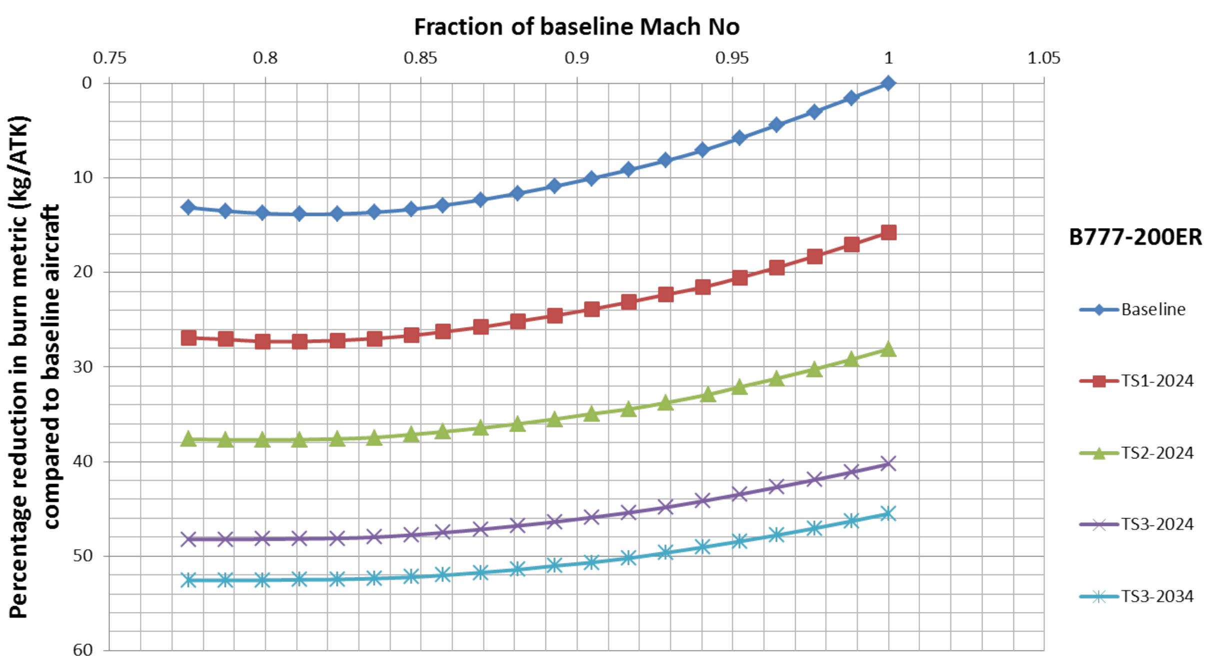


Figure 12. B777-200ER Mission specification variation effect on fuel burn.

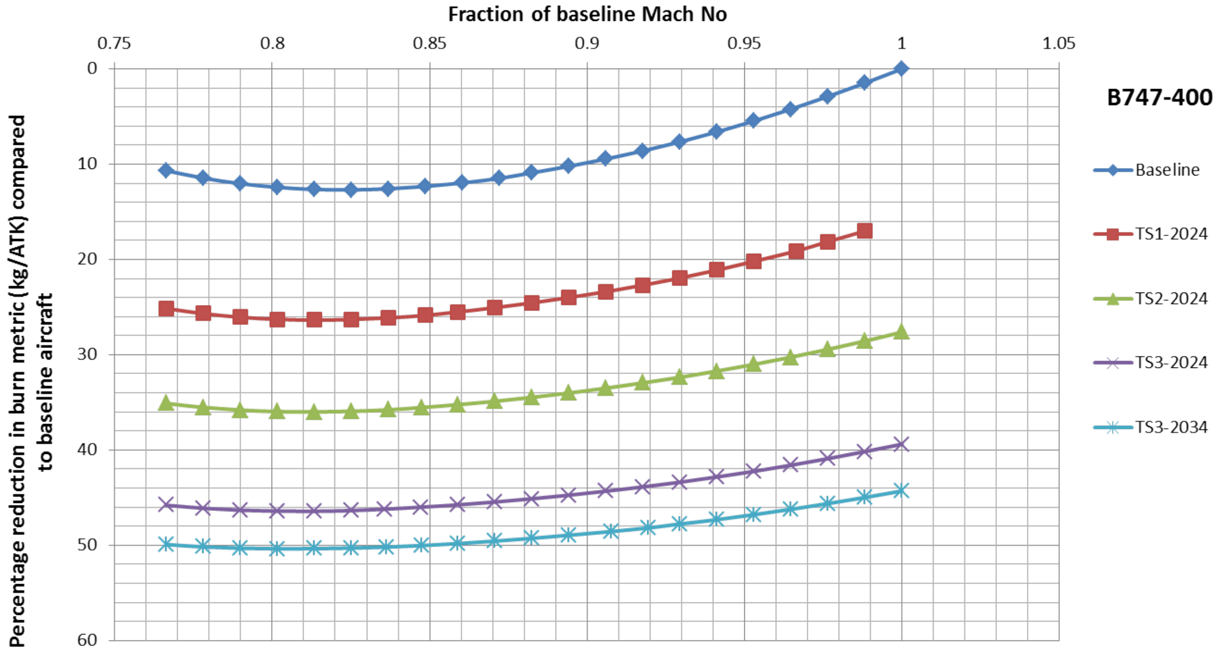


Figure 13. B747-400 Mission specification variation effect on fuel burn.

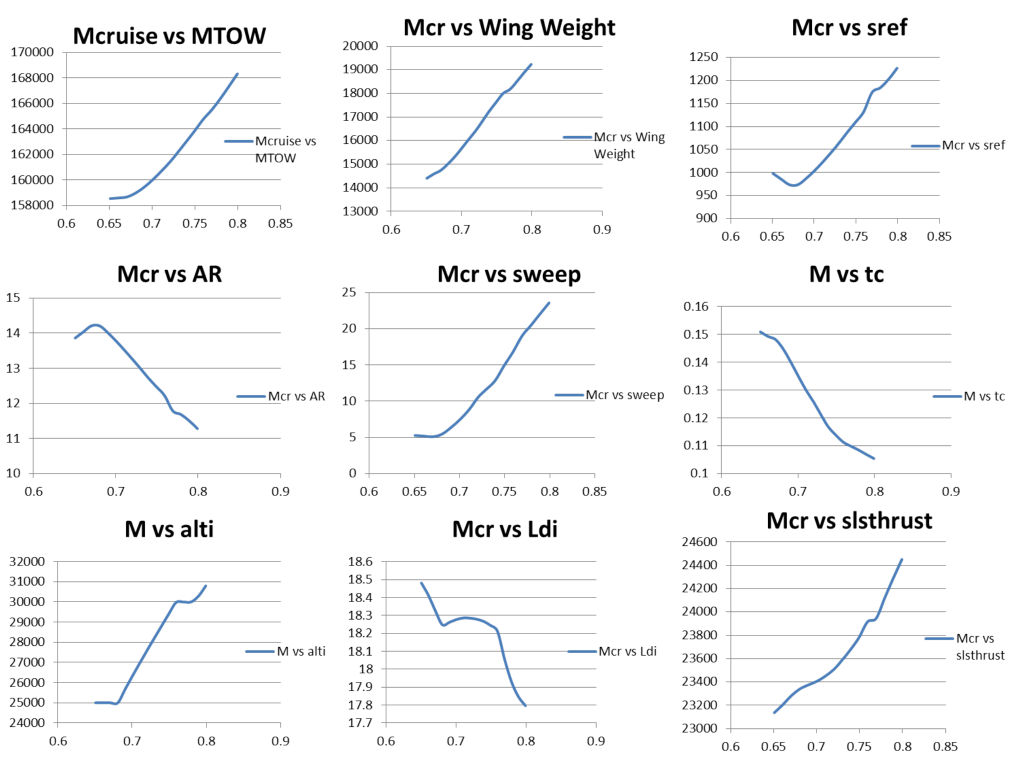


Figure 14. The plot indicates the effect of cruise Mach Number on design variables. The weights/thrust are specified in terms of pounds(lbs), the area is in ft $\hat{2}$, sweep is in degrees and altitude in ft.

B. R1 Range Reduction

R1 range reduction is also an effective method for the reducing the fuel burn metric for most of the aircraft. Reduction of R1 range results in a smaller mission being performed. A reduction in the fuel weight coupled with weight savings from smaller fuel tanks results in a significantly lighter aircraft. This allows the wing area to be reduced which increases the aspect ratio contributing to a reduction in induced and parasite drag. This reduces the cruise thrust requirement and consequently the fuel burn.

It is observed that an R1 reduction is more effective for the larger aircraft (both in terms of MTOW and in terms of R1 range). When redesigned for smaller R1 ranges for the same payload, the fuel weight reduction coupled with the requirement for smaller engines and a lighter structure results in considerable improvements in the fuel burn characteristics for these aircraft. Figure 15 indicates the effect of the optimization process on the design variables.

At higher technology levels, like cruise Mach number, the R1 range variation is effective for fuel burn reduction for the larger aircraft. However, the effectiveness of R1 range variation is less for improved technology aircraft compared to the baseline aircraft. The Figs. 16,17,18,19,20 indicate the reduction of fuel burn with R1 Range.We see that at higher technology levels the optimal R1 range tends towards values higher than the baseline R1 range.

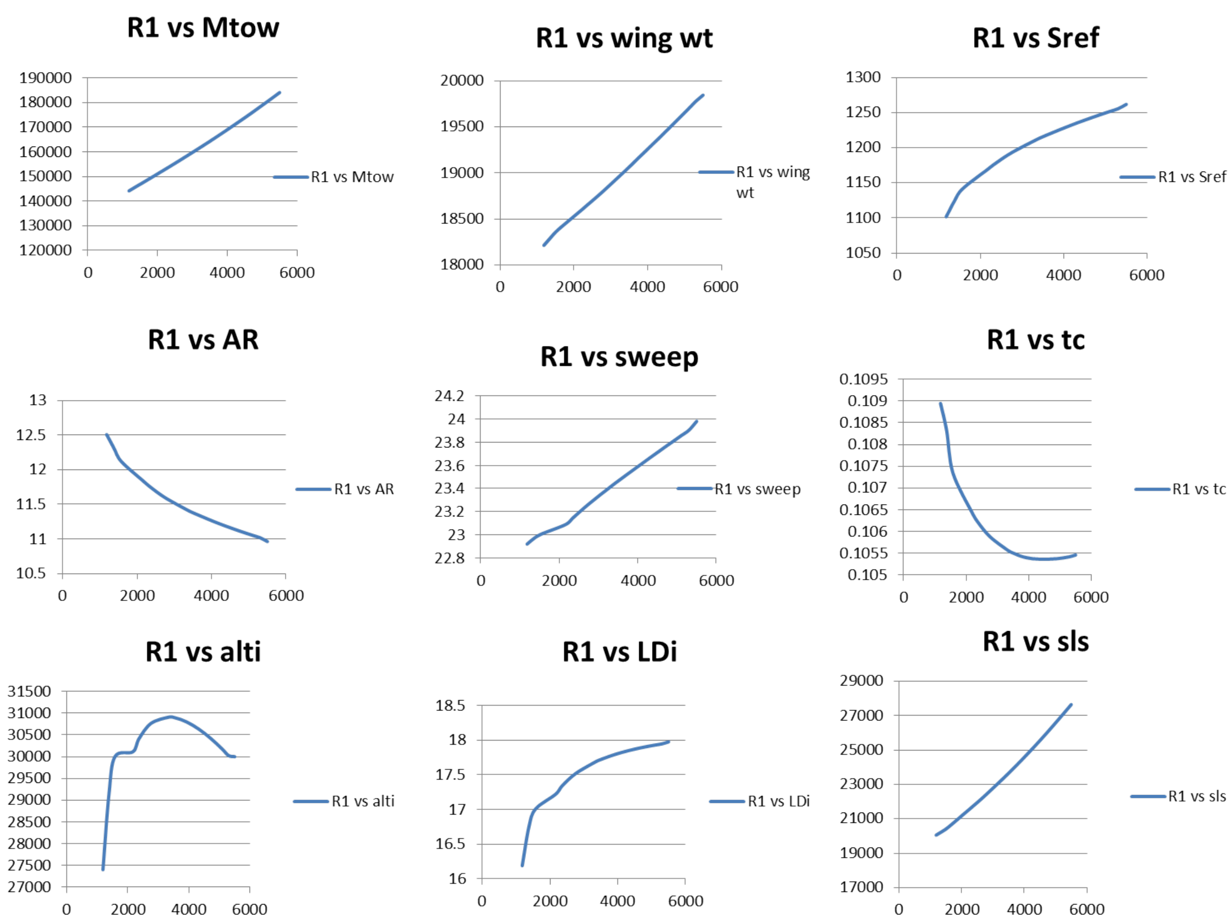


Figure 15. Effect of R1 range variation on design variables. The weights/thrust are specified in terms of pounds(lbs), the area is in ft $\hat{2}$, sweep is in degrees and altitude in ft.

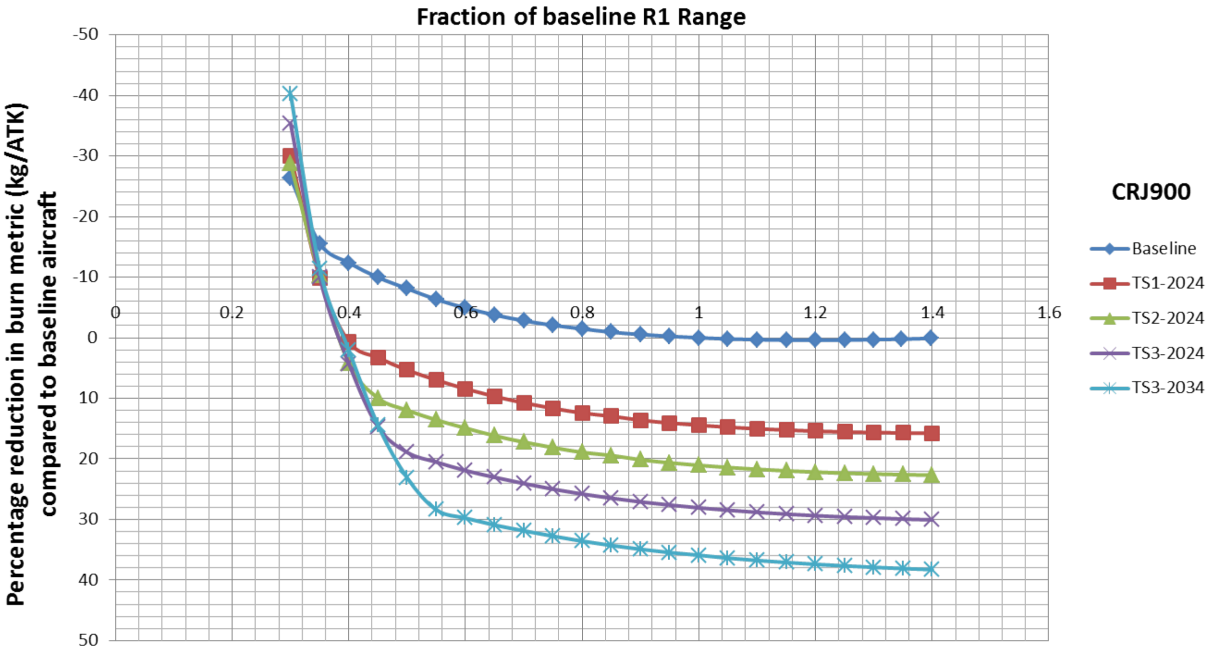


Figure 16. CRJ900 Mission specification variation effect on fuel burn.

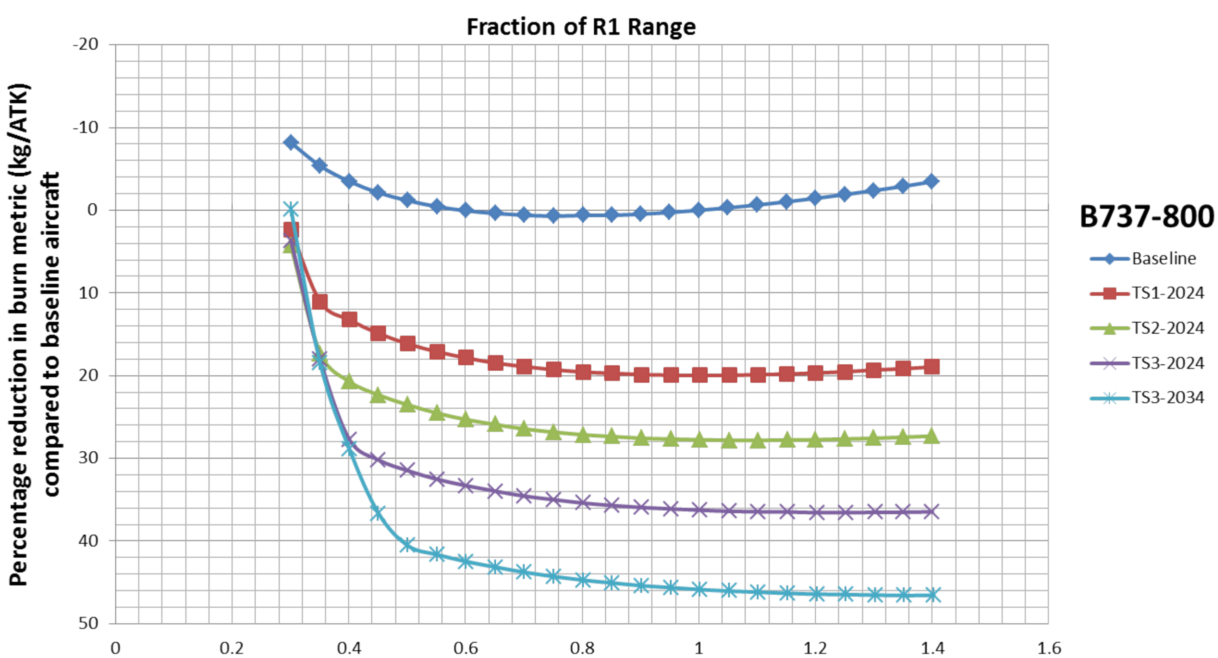


Figure 17. B737-800 Mission specification variation effect on fuel burn.

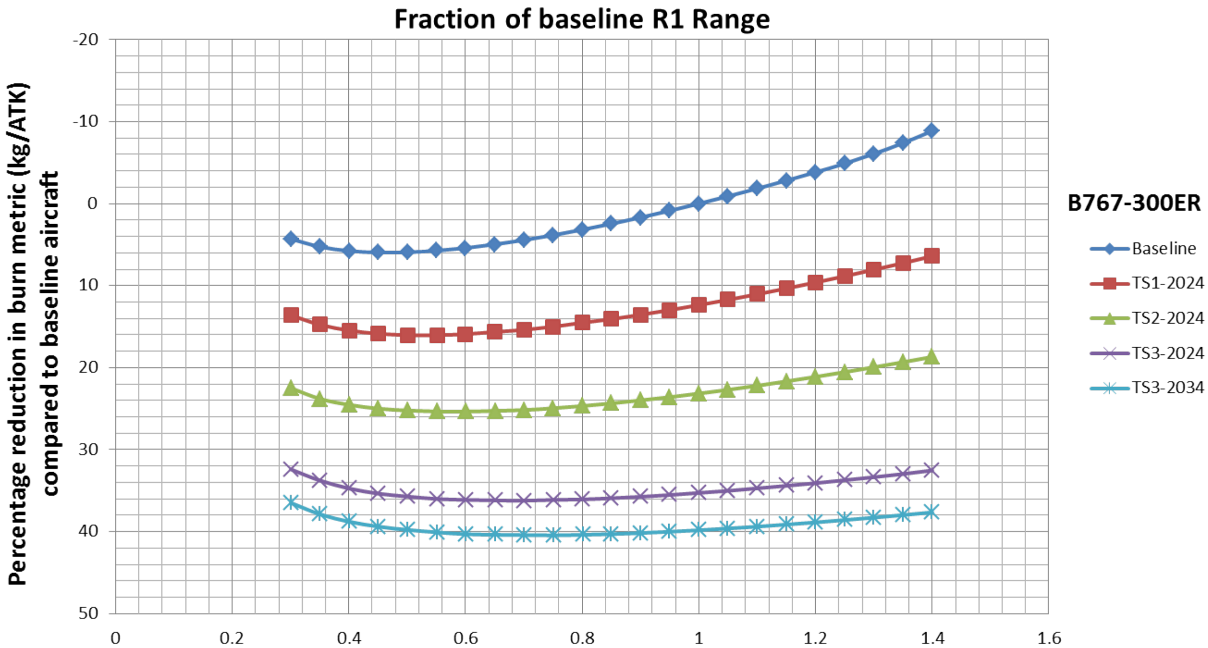


Figure 18. B767-300ER Mission specification variation effect on fuel burn.

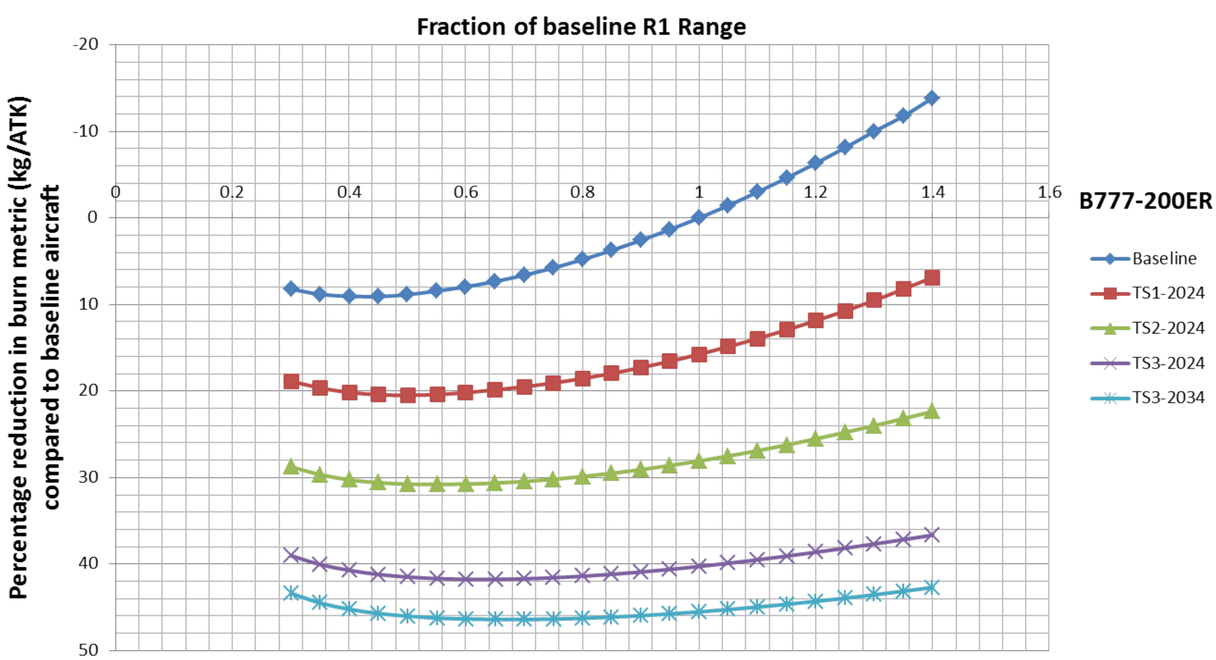


Figure 19. B777-200ER Mission specification variation effect on fuel burn.

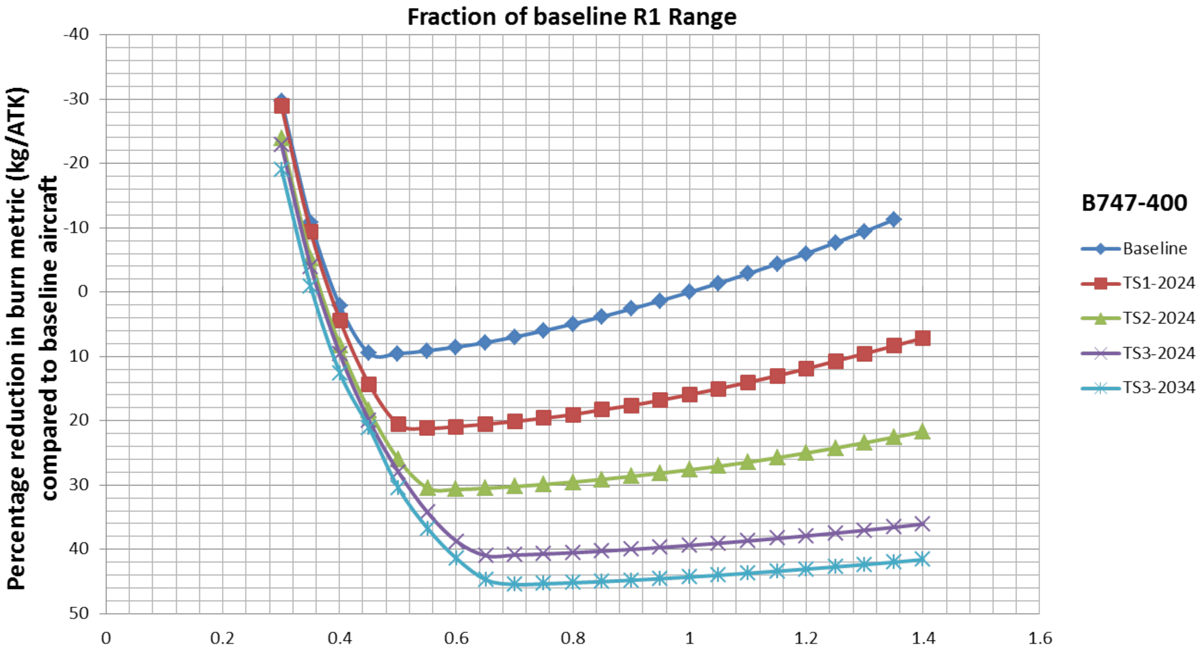


Figure 20. B747-400 Mission specification variation effect on fuel burn.

C. Wing Span Variation

Increase in the wing span results in reduced induced drag. However in most cases the increase in the wing area and the associated increase in the structural weight overcome the effect of reduced induced drag. For the smaller aircraft though (CRJ-900) increasing the wing span is fairly effective in bringing down the fuel burn metric. For the larger aircraft, the plots clearly indicate that optimal span selection is imperative for improved fuel burn characteristics. However, for most of the aircraft, the baseline aircraft are designed with wing spans close to the optimum and so variation from the baseline value does not bring down the fuel burn. There is evidence that unconventional configurations like strut and truss braced wings can reduce fuel burn by increasing wing span, but those have not been looked at in this study.

The effect of wing span increase was not as effective with higher technology aircraft. The Figs. 22, 23, 24,25, 26 show the variation of fuel burn metric with wing span.

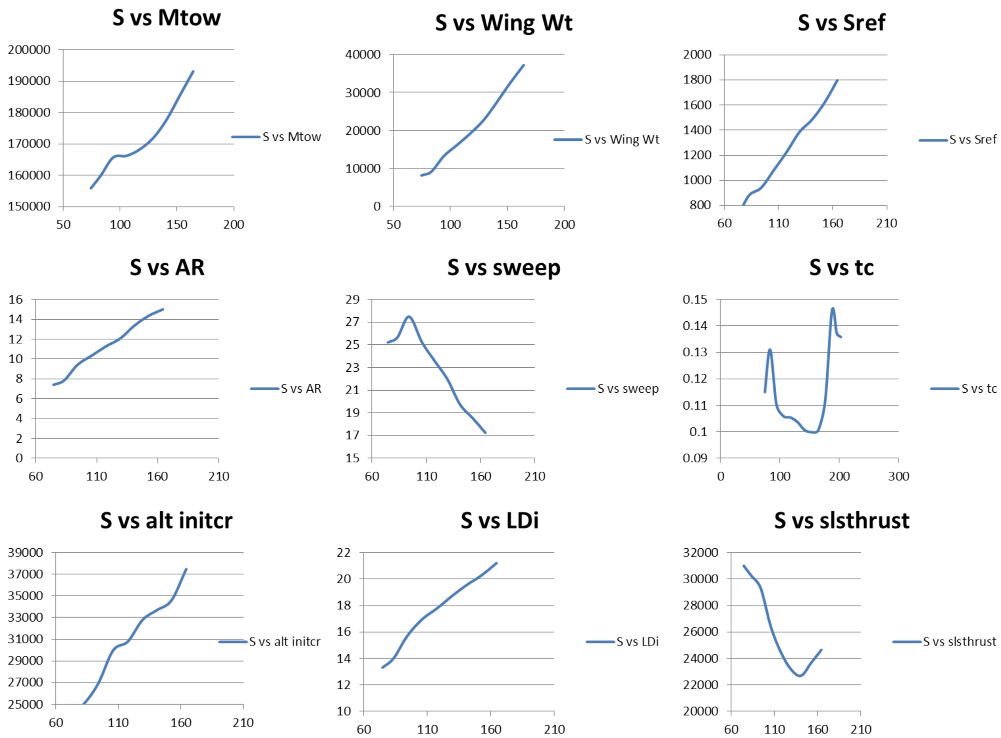


Figure 21. Effect of span variation on design variables. The weights/thrust are specified in terms of pounds(lbs), the area is in ft2̂, sweep is in degrees and altitude in ft.

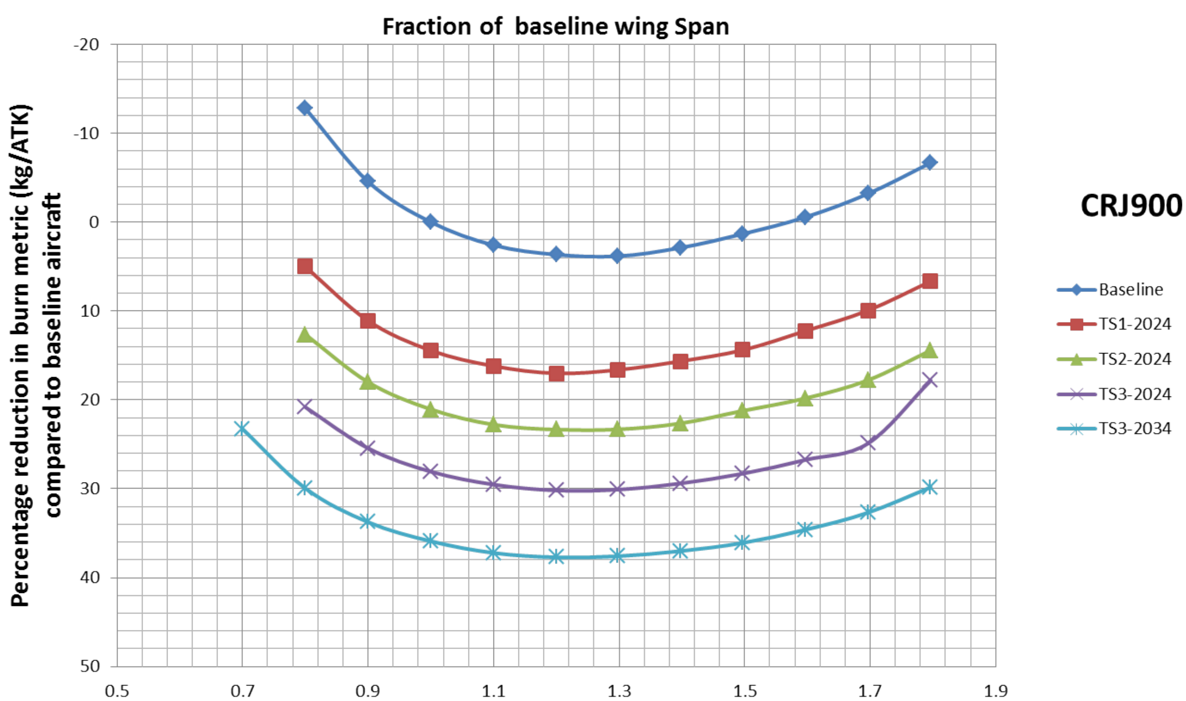


Figure 22. CRJ900 Mission specification variation effect on fuel burn.

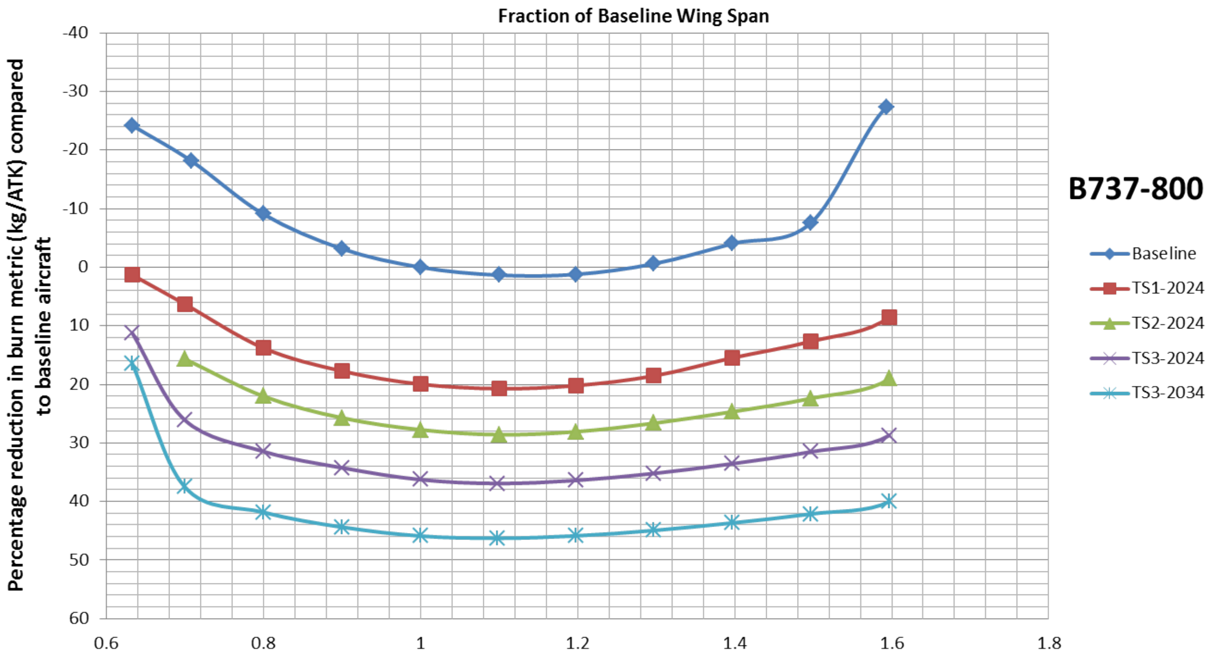


Figure 23. B737-800 Mission specification variation effect on fuel burn.

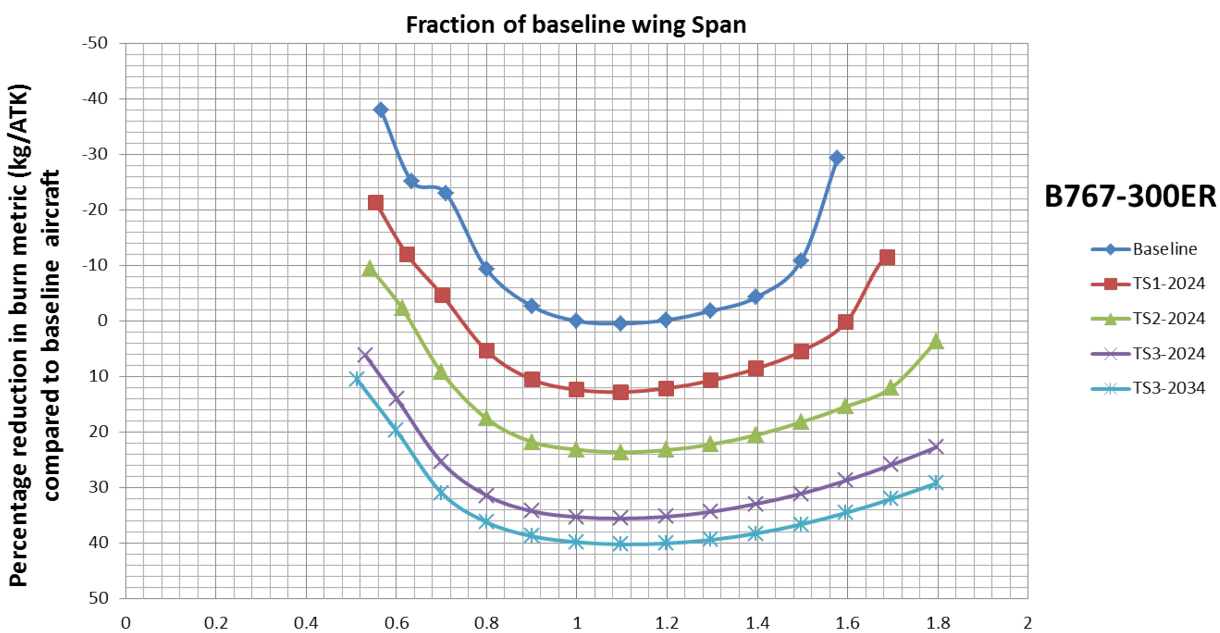


Figure 24. B767-300ER Mission specification variation effect on fuel burn.

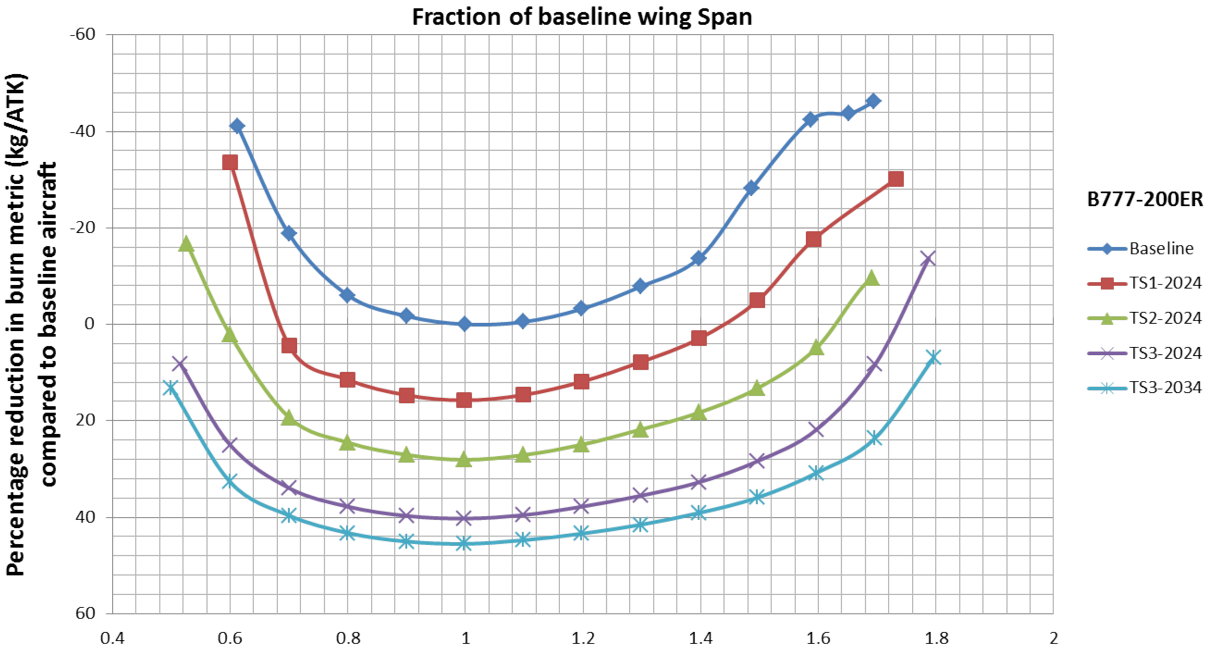


Figure 25. B777-200ER Mission specification variation effect on fuel burn.

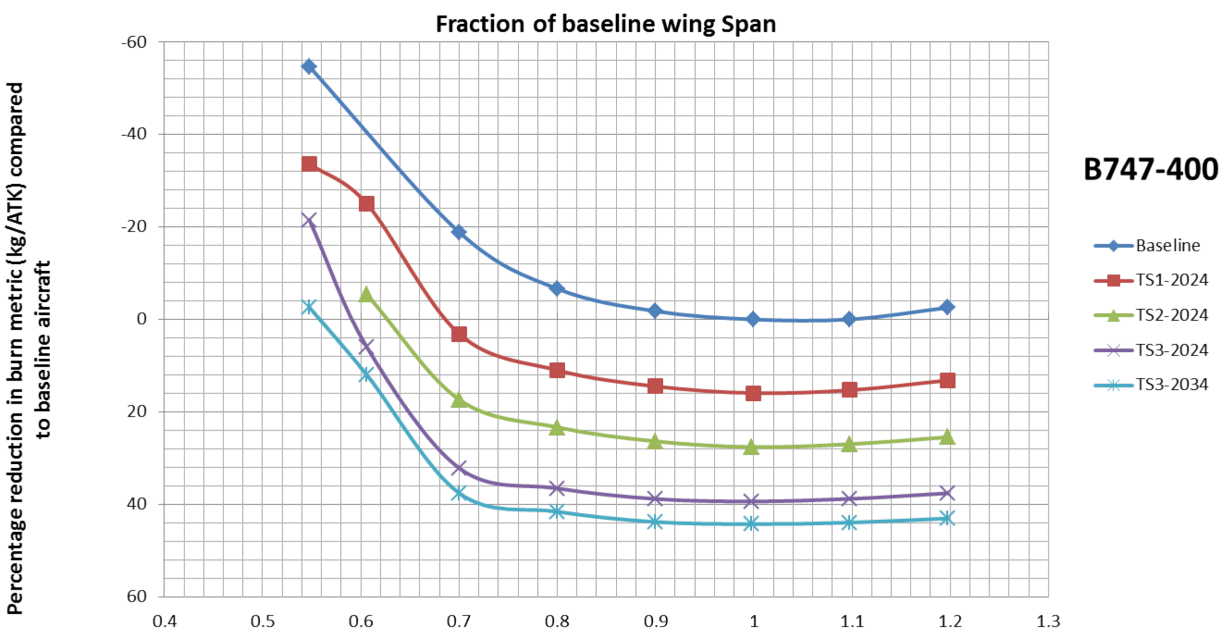


Figure 26. B747-400 Mission specification variation effect on fuel burn.

D. Summary of the results

The results obtained form the redesign of aircraft (of all classes and technology levels) for minimum fuel burn with mission specification changes are tabulated below in Figs 27, 28, 29,30, 31. These contain the results for individual and combinations of mission specification changes.

PARAMETER VARIED	BASELINE	MACH	RANGE	SPAN	MACH-RANGE	SPAN-MACH	Span Mach Range
				% fuel burn reduction			
Technology Level							
Baseline		6	0	4	6	15	17
TS1-2024		20	16	17	21	27	30
TS2-2024		27	23	23	27	32	35
TS3-2024		33	30	30	34	38	42
TS3-2034		41	38	38	43	45	49

Figure 27. CRJ900 Mission specification variation effect on fuel burn.

PARAMETER VARIED	BASELINE	MACH	RANGE	SPAN	MACH-RANGE	SPAN-MACH	Span Mach Range
				% fuel burn reduction			
Technology Level							
Baseline		8	1	1	9	13	13
TS1-2024		27	20	21	27	30	30
TS2-2024		33	28	29	34	37	37
TS3-2024		41	37	37	42	44	44
TS3-2034		50	47	46	51	52	53

Figure 28. B737-800 Mission specification variation effect on fuel burn.

PARAMETER VARIED		MACH	RANGE	SPAN	MACH-RANGE	SPAN-MACH	Span Mach Range
				% fuel burn reduction			
Technology Level							
Baseline		7	6	0	13	11	15
TS1-2024		19	16	13	23	21	24
TS2-2024		29	25	24	31	31	32
TS3-2024		40	36	36	41	42	42
TS3-2034		44	40	40	45	46	46

Figure 29. B767-300ER Mission specification variation effect on fuel burn.

PARAMETER VARIED		MACH	RANGE	SPAN	MACH-RANGE	SPAN-MACH	Span Mach Range
				% fuel burn reduction			
Technology Level							
Baseline		14	9	0	23	18	24
TS1-2024		27	20	16	33	30	34
TS2-2024		38	31	28	41	40	43
TS3-2024		48	42	40	50	50	51
TS3-2034		53	46	46	54	55	55

Figure 30. B777-200ER Mission specification variation effect on fuel burn.

PARAMETER VARIED		MACH	RANGE	SPAN	MACH-RANGE	SPAN-MACH	Span Mach Range
				% fuel burn reduction			
Technology Level							
Baseline		**13**	**10**	**0**	**21**	**15**	**21**
TS1-2024		**26**	**21**	**16**	**31**	**28**	**31**
TS2-2024		**36**	**31**	**28**	**39**	**37**	**39**
TS3-2024		**46**	**41**	**39**	**48**	**47**	**48**
TS3-2034		**50**	**45**	**44**	**51**	**51**	**52**

Figure 31. B747-400 Mission specification variation effect on fuel burn.

The trends for the individual missions specification changes for aircraft have already been described above. It is interesting to note that a combination of 2 or 3 of the mission specification changes results in further improvements in the fuel burn. At the minimum, a combination produces the same improvements as the best individual improvement but in most cases a combination of mission specification changes results in greatly reduced fuel burn metric compared to the baseline aircraft for the same aircraft class. This is exceedingly useful as for most aircraft it might not be realistic to go to the optimal point for an individual mission specification. For example for the Boeing 777-200ER class of aircraft, it might not be realistic to move from a Mach 0.84 to a Mach 0.68 (14% reduction in fuel burn) nor might it be feasible to go from an R1 range of 5750 nm to 2500 nm (9% reduction in fuel burn). However it might be possible to use a combination of mission specification changes to have an aircraft designed for a cruise Mach number of 0.75 and an R1 range of 4000 nm and obtain an improvement similar to that obtained from optimal individual mission specification changes.

The results for the improved technology designs without incorporating mission specification changes indicate that significant reductions in fuel burn are possible in the future for aircraft of all classes due to technology itself. Close to 40% reductions in fuel burn are observed for all aircraft for the 2034 Aggressive case(TS3-2034). Even for TS3-2024 upper bounds of 30%-40% reduction are observed for most of the aircraft. With mission specification changes these values move towards 50 % reduction in fuel burn by 2034 for the TS3 technology scenario which if feasible will definitely take us very close to achieving the fuel burn reduction goals that the industry has set.

A comparison of the effect on mission specification changes across the different aircraft classes (for baseline aircraft) is shown in Fig 32.

AIRCRAFT	Mach	Range	Span
CRJ900	6	0	4
B737-800	9	1	1
B767-300ER	7	6	0.5
B777-200ER	14	9	0
B747-400	13	10	0

Figure 32. Summary of the effects of mission Specification changes.

The summary of the results for the baseline technology aircraft clearly indicates that R1 range reduction is more effective for larger aircraft and its effect decreases for the smaller aircraft. Wing span increase has the opposite effect with the smaller aircraft benefiting from span increase.Cruise Mach number is very effective for all the aircraft especially for the larger ones.

IV. Conclusions

The effect of making changes to the design mission specification of aircraft is studied for aircraft of various classes and at various technology levels. The baseline aircraft are modelled using the conceptual design environment PASS coupled with an inhouse propulsion analysis module and a climb module and then redesigned to study the effect of improved technology and mission specification changes on fuel burn. Critical to this analysis is the off-design analysis capability of the propulsion module using GPR based surrogate models of the compressor map, and the climb module in order to accurately predict the fuel burn for the reduced Mach and reduced R1 range cases. The studies performed above indicate that reduction of cruise Mach number and R1 range lead to variants with significantly reduced fuel burn(upto 25% reduction). Combinations of these mission specifications are even more effective. Interestingly these changes are effective in reducing the fuel burn of improved technology aircraft as well. Thus the redesign of aircraft with mission specification changes is a promising option for achieving the desired fuel burn reductions for the commercial fleet.

However for such designs to be practical from an aircraft manufacturer and an airline perspective,the economic and fleet level impact of making these mission specification changes, the effect on airport infrastructure and the NAS have to be looked at as well. This has been done in Project 43 where members of the other Tasks 2,3,and 4 have looked at the above stated effects in detail. Details of those results are not shown here but have been described in considerable detail in the Project 43 report of the FAA.

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