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DESIGN, MODEL, AND VIRTUALLY FLY: INVESTIGATION OF THE B-1A CRUISE PERFORMANCE WITH F101 ENGINES COMPARED WITH ITS RE-ENGINED PERFORMANCE USING F119 ENGINES

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ABSTRACT

This paper examines application of AEDSYS and MATLAB design tools to virtually fly an engine in a platform through a mission. The primary objective of this effort was to develop the procedures for this process as an instructional tool. The secondary objective was application of the process to an actual case study, the re-engine of the B-1A. The resulting modular software uses performance data from engine models for the F101, F119, and a cadet designed engine built in AEDSYS; a B-1A drag polar model; as well as atmospheric and geospatial mapping tools available in MATLAB. The resulting simulation provides a relatable means of presenting this complicated information.

This tool gives the cadets the opportunity to virtually fly their engine. This visualization gives them full insight into how the integrated system performs. Aside from providing a great means of discussing many aspects for consideration in engine design, it also provides an incentive to develop a higher performance engine through competition.

INTRODUCTION

An advantage of an undergraduate aircraft design capstone is the ability to design, build, and fly. The complexity associated with advanced engine design makes such an option time and cost prohibitive for air-breathing engine capstones. The desire for engine students to see the outcome of their labor was the motivation to develop a virtual simulation.

The capstone assignment for the class of 2010 was to re-engine the B-1A. Table 1 shows the three configurations for comparison. This assignment allowed for model verification by testing the baseline system performance of the B-1A with F101s. Next was an incremental comparison of performance with F119s. This aircraft is exactly the same except for smaller nacelles and associated drag designated the B-1Aii. Finally cadets designed their own engine, the F483, using the original B-1A nacelles. This aircraft has the same drag polar as the original aircraft and will be designated the B-1Aiii. This incremental approach helped cadets better understand many issues with their engine models as well as integration issues. It also built confidence through practice.

Table 1. Configurations for USAFA 2010 capstone study.

Configuratio n	Aircraft	Engines	Color code
B-1A	B-1A	4 F101s	Red
B-1Aii	B-1A smaller nacelles	4 F119s	Blue/cyan
B-1Aiii	B-1A	4 F483s	Green

The virtual test was designed for a cruise competition between the three B-1A configurations. Each aircraft started at its cruise altitude and Mach for maximum range at the same weight. Then each aircraft flew from Diego Garcia, over Baghdad, and then over Afghanistan in a race-track. Flight Mach and altitude adjusted to maximize range based on weight as fuel burned. Additionally, each plane automatically refueled whenever required.

Further studies were conducted to answer F119 re-engine performance questions. This tool was used to estimate and demonstrate first order performance predictions. Could the B-1A supercruise with F119s? If so, for how long and how far? How would this performance compare to the performance with F101s? What would be the trade-offs?

The development of the software ensues. First, the individual modules for the engines, aircraft, atmosphere, and geospatial environment are discussed. Next, the system level performance for each aircraft configuration using cruise is developed. Finally, the performance investigations for B-1A re-engined performance are presented.

NOMENCLATURE

BR: Bypass Ratio
C_{D0}: Profile Drag Coefficient
D: Drag
F: Uninstalled Thrust
FPR: Fan Pressure Ratio
GE: General Electric
K_1: Induced Drag Coefficient
L: Lift
L/D: Lift to Drag Ratio
LOT: Level of Technology
OPR: Overall Pressure Ratio
P_s: Weight Specific Excess Power
PW: Pratt & Whitney
RF: Range Factor
S: Aircraft Planform Area
SFC: Uninstalled Thrust Specific Fuel Consumption
SLS: Sea-Level Standard/Sea-Level Static
SLUF: Steady Level Unaccelerated Flight
T: Installed Thrust
T_{av}: Thrust Available (engine dependent)
T_{req}: Thrust Required ie Drag in SLUF (aircraft dependent)
TSFC: Installed Thrust Specific Fuel Consumption
TIT: Turbine Inlet Temperature (T_{t4})
T_{t4}: Total Temperature Entering Nozzle Guide Vanes
T_{t7}: Total Temperature in the Afterburner
W: Weight
W_{empty}: Empty Aircraft Weight
W_{init}: Initial Weight at Start of Cruise
W_{refuel}: Refuel Weight = $1.1W_{empty}$
W_{res}: Weight of Reserve Fuel = $10\%W_{empty}$
W_{TOmax}: Max Take Off Weight
dt: Time Interval (10 minutes)
q: Dynamic Pressure ($\frac{1}{2}\ \rho V^2$)
ΔW: Weight Change (Weight of Fuel Burned)
θ_0: Total Temperature of Freestream Divided by 518.67R
θ_{0break}: Engine Control Break Value for OPR to T_{t4} Limited

1 MAIN MODULES

In keeping with systems engineering practices the full simulation is modular. This allows for verification of each module and final validation of the total program. Additionally, the model development process of model, verify, and compare is demonstrated for cadets. There are four verified components necessary before flying a mission. These four main modules are: 1. engine 2. aircraft 3. atmosphere and 4. geospatial. Each of the engine models was developed in AEDSYS. The other three modules were developed in Matlab. These four modules were then integrated into a program loop that can be adapted to user investigations. Each of the four main module's development and verification will be described.

1.1 Engine Module

The first module is for the engine. Each engine model was built using AEDSYS. The two engines presented here are the F101-GE-102 and the F119-PW-100. Each engine is a relatively low bypass mixed exhaust turbofan with afterburner. The data required were the design choices: overall pressure ratio, bypass ratio, and fan pressure ratio. Additionally, the design temperature limits at the nozzle guide vane and afterburner, T_{t4} and T_{t7} respectively, were required. Finally the design Mach, altitude, and mass flow rate were required.

Most published data is for uninstalled engine performance at sea level static. An iterative process ensued where well-reasoned guesses for design Mach, altitude, and mass flow rate were made. Each engine was then tested at sea level static and performance compared to published data. The results of this process were reasonable engine models for the F101 and F119. The sea level static data was the only data available for verification and so engine performance is extrapolated at other conditions.

1.1.1 F101-GE-102

The F101-GE-102 engine was designed in the 1960-1970's and first flew in the B-1A in 1974. (1) It has a relatively high bypass ratio engine, nearly 2.0 compared to fighter aircraft engines which are typically 0.5 or lower. (2) This helps the F101 with fuel economy for long range missions, but also limits the aircraft's ability to supercruise due to the requisite larger diameter. The other detractors to supercruise are the early level of technology and correspondingly low turbine inlet temperature.

1.1.1.1 F101 Model

For simplicity, the F101-GE-102 engine data in Table 2 came directly from Mattingly's text. The level of technology 2 data, for the decade from 1965-1985 was used for all component efficiencies and figures of merit. The T_{t7} used was assumed to be higher then LOT 2, which was only 3000 R, thus 3600 R was used. The design flight condition used was SLS since the θ_{0break} for this era was 1.0.

Table 2. F101-GE-102 Data. (3)

Design Choices	OPR	26.8
	FPR	2.31
	BR	1.91
Design Limits	T_{t4}	3010 R
	T_{t7} (LOT 3)	3600 R
Flight Conditions	Mach	SLS
	Altitude	SLS
	Airflow SLS	356 lbm/s

1.1.1.2 F101 Verification

In order to verify this engine model, the mil and max power performance at SLS were tested and compared to published uninstalled values. Table 3 shows the resulting verification. The model is very accurate for SLS thrust in mil power. Although changes could be made to the model to get closer accuracy to published data at other points, this first level effort traces back directly to data available to cadets. Therefore, this model was used as reasonable. Since most investigations were in mil power, the engine performance predictions were fairly reasonable.

Table 3. F101-GE-102 Verification of Model.

	F_{mil} (lbf)	F_{max} (lbf)	S_{mil} (1/hr)	S_{max} (1/hr)
SL Pub (3)	17,390	30,780	0.562	2.460
Calculated	17,539	32,609	0.599	2.145
% error	0.9%	-5.9%	-6.6%	12.8%

The values required for calculating actual fuel burn rate are the throttle set installed thrust and thrust specific fuel consumption at each point (throttle set, refers to matching $T_{av}=T_{req}$ on the throttle hook). In order to simplify the model, the mil power uninstalled thrust and thrust specific fuel consumption were used at each discrete Mach and altitude. These values were easily obtained using the AEDSYS engine test Mach and altitude sweeps. Figure 1 shows the F101 model uninstalled thrust in mil power for several discrete altitudes. The final model includes all Mach numbers presented and all altitudes from 0 to 60 kft in increments of 5,000 ft. Figure 2 shows the F101 model values for uninstalled thrust specific fuel consumption.

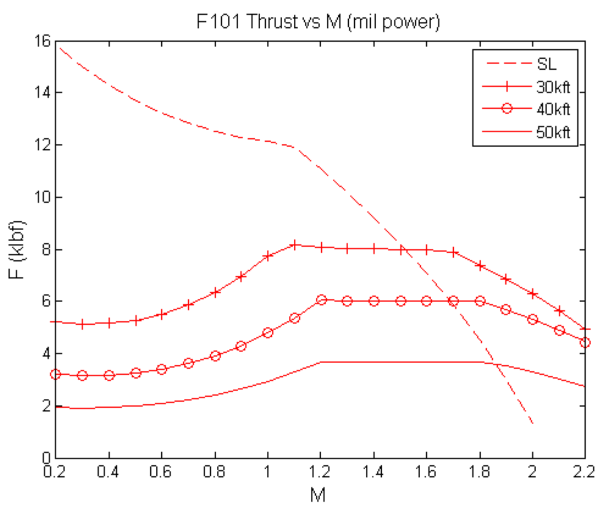

Figure 1. F101 engine model uninstalled thrust vs Mach number in mil power.

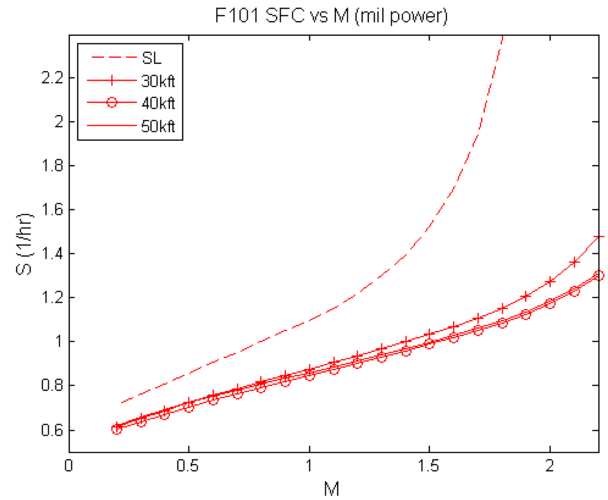

Figure 2. F101 engine model uninstalled thrust specific fuel consumption vs Mach number in mil power.

1.1.2 F119-PW-100

The F119-PW-100 was designed in the 1980-1990's and first flew in the YF-22 in 1990 and in the F-22 in 1997. (4) It has been called a "leaky turbojet" by the father of the F119, Mr. Frank Gillette, because of its extremely low bypass ratio. The F119 gets its ability to supercruise from its high turbine inlet temperature. Additionally, the low bypass ratio helps increase the specific thrust making for a smaller diameter engine that limits profile drag. The low bypass ratio causes a higher relative thrust specific fuel consumption compared to the F101, but the higher level of technology and much higher thrust without an afterburner aid in supercruise performance.

1.1.2.1 F119 Model

The F119-PW-100 engine data comes from 2008 Jane's All the World's Aircraft where available. The overall pressure ratio is a reasonable estimate for a fighter. The fan pressure ratio was determined using AEDSYS to determine the optimum ratio to achieve $P_6=P_{16}$, ie the Kutta condition at the mixer plane. Table 4 shows the range of values with selected model values underlined.

Table 4. F119-PW-100 Data at design point (4).

Design Choices	OPR (est.)	27-30
	FPR (Kutta)	5.0-6.0
	BR	0.3-0.45
Design Limits	T_{t4} (LOT 4)	3600 R
	T_{t7} (LOT 4)	4000 R
Flight Conditions	Mach (est.)	1.3
	Altitude (est.)	30 kft
	SLS mass flow	270 (lbm/s)

The level of technology 3 data, for the decade from 1985-2005 was used for all component efficiencies. The LOT 4 data was used for T_{t4} and T_{t7} to achieve reasonable thrust levels. The design flight condition used was M=1.3, alt=30kft since this has a corresponding θ_{0break} = 1.06 and makes sense for supercruise requirement.

1.1.2.2 F119 Verification

In order to verify this engine model, the mil and max power performance at SLS were tested and compared to published uninstalled values. Table 5 shows the resulting verification. Because only the SL maximum thrust is available, the confidence in this model is minimal. However, the process of verification has been enforced.

Table 5. F119-PW-100 Verification of Model.

	F_{mil} (lbf)	F_{max} (lbf)	S_{mil} (1/hr)	S_{max} (1/hr)
SL Pub (3)	N/A	35,000	N/A	N/A
Calculated	25,966	36,855	0.93	1.62
% error		-5.3%		

The values required for the simulation are the mil power uninstalled thrust and thrust specific fuel consumption at each discrete Mach and altitude. Figure 3 shows the uninstalled F119 model thrust versus Mach number. The higher thrust levels compared to the F101 are due to the cycle type, lower bypass, as well as the higher turbine inlet temperature. These design choices in combination with advance components overcome the 30% smaller mass flow rate.

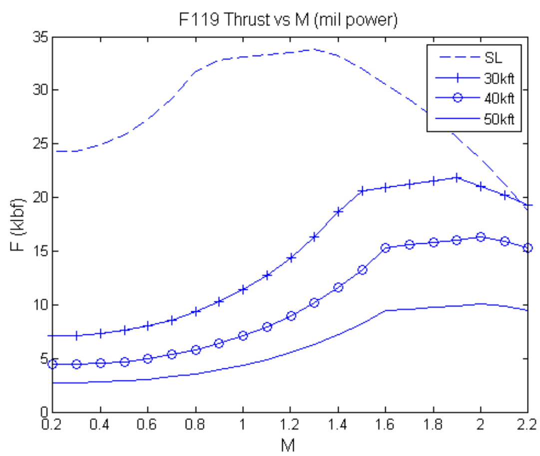

Figure 3. F119 engine model uninstalled thrust vs Mach number in mil power.

Figure 4 shows the uninstalled thrust specific fuel consumptions for the F119 engine model in mil power. Here the higher SFC, compared to the F101, is a function of the lower bypass and higher turbine inlet temperature. For this first level effort the throttle hook performance at partial settings is not taken into account.

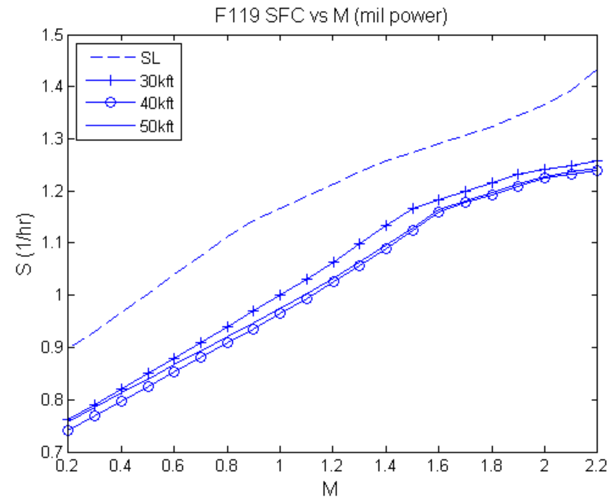

Figure 4. F119 engine model uninstalled thrust specific fuel consumption vs Mach number in mil power.

1.2 Aircraft Module

The only data required for modeling the aircraft are its Weight, Wing Area, and Drag Model. This is because the analysis is in cruise and the steady, level, unaccelerated flight assumption simplifies the aircraft model. Flaps and landing gear are up. The aircraft is assumed to cruise at low angles of attack. Even a simplified model for wing sweep is applied to the drag model.

1.2.1 B-1A Weight and Wing Area

Even though each configuration will have a slightly different weight, the weights and wing area in Table 6 were used for all three configurations. The initial aircraft weight was estimated as the weight fraction of maximum takeoff weight needed to reach the initial cruise altitude. The estimate used for this program was that the aircraft weight decreased 12% from max take-off weight, through climb to the cruise altitude. Thus, the initial weight for each B-1A was estimated to be the same, W_{init}=0.88 W_{TOmax}. The minimum weight for cruise prior to mandatory refuel was 10% greater than empty weight. Thus, as each aircraft burned fuel during cruise, it was automatically refueled when its weight dropped below this limit. The verification for this model was published data.

Table 6. B-1A weights and wing area.

W_{TOmax} (1)		477,000 lbf
W_{empty} (1)		192,000 lbf
W_{init}	0.88 W_{Tomax}	419,760 lbf
W_{res}	10% W_{empty}	19,200 lbf
W_{refuel}	1.1 W_{empty}	211,200 lbf
S (1)		1,950 ft^2

1.2.2 B-1A Drag Polar

The second module models the B-1A aircraft drag. Since the B-1A is a swept wing aircraft, the drag polar was simplified such that wing sweep was only a function of Mach number. From Mach=0-0.8, the wing sweep was 25 deg. From Mach=0.8-1.2, the wing sweep was 65 deg. Finally, from Mach=1.2-2.2, the wing sweep was 67.5 deg. The K_2 value was set to zero. Then the C_{D0} and K_1 values were determined using wind tunnel data. A second C_{D0} was estimated based on the decreased wetted area using F119 engines vs F101s. The result of this drag data simplification is shown in Figure 5.

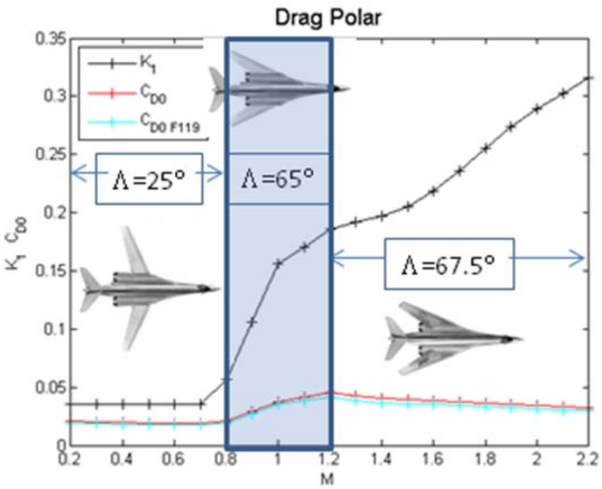

Figure 5. B-1A Simplified Drag Polar, K_2=0.

1.2.3 B-1A Drag Polar Verification

In order to verify the drag polar model, these values for K_1 and C_{D0} were used to determine the drag coefficient vs. Mach number for two different coefficients of lift. These relatively low lift coefficients, 0.2 and 0.4, were chosen because they are realistic bounds for cruise legs.

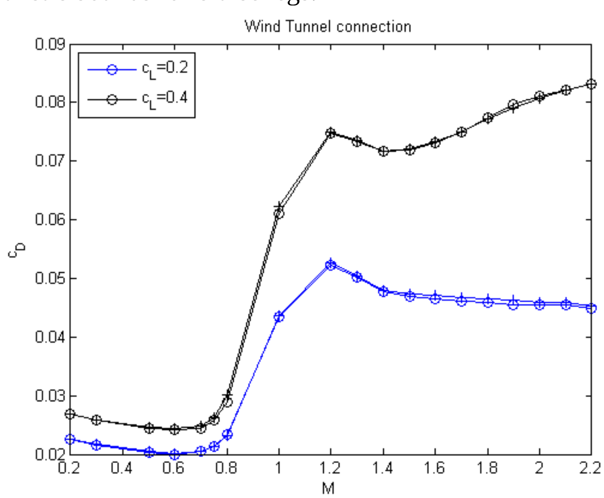

Figure 6. B-1A Drag Coefficient vs Mach number verification to consolidated wind tunnel data (5).

As shown in Figure 6, the modeled drag coefficient closely follows the wind tunnel data. The circle data is the model output and the +'s are from the wind tunnel.

1.3 *Atmosphere Module*

The atmosphere model in Matlab is the international standard atmosphere model using the function atmosisa. The temperature, speed of sound, pressure, and density are each available as a function of altitude. For completeness and to show that unit conversions were made from SI to English, several altitude properties were checked. This level of verification shows the cadets the proper way to check models and provides confidence in the entire process. Figure 7 shows the resulting map of lines of constant θ_0. The line of θ_0=1 goes through SLS, as it should, verifying the model.

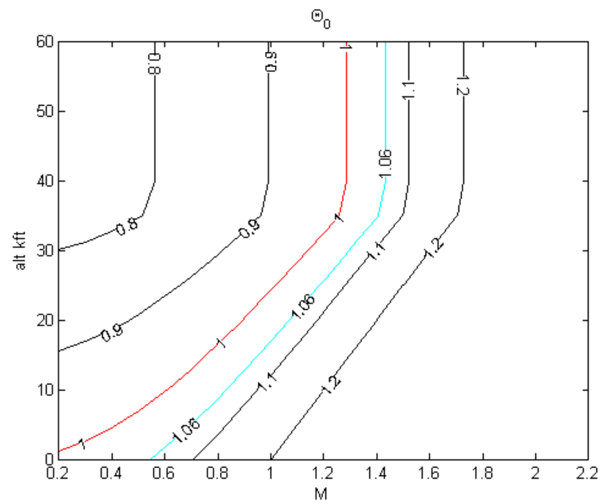

Figure 7. Lines of constant θ_0 from the atmos model.

1.4 *Geospatial Module*

Finally, the ability to generate great circle tracks is embedded in Matlab software. The function geoshow is manipulated to build the tracks. The verification for this model was simply to put in correct latitudes and longitudes and tracks for the desired waypoints and ensure they plotted correctly on the map. In other words, Diego Garcia, when plotted corresponded to Deigo Garcia. Table 7 shows the corresponding latitudes and longitudes used for way points.

Table 7. Cruise Mission Way Points.

	Latitude	Longitude
Diego Garcia	-7.33	72.45
Baghdad	32.33	44.36
Afghanistan	33.00	65.00

2 CRUISE PERFORMANCE

Now that each of the modules have been modeled and verified, they can be integrated into a mission. For simplicity, the virtual program was limited to investigate cruise performance. For each aircraft, the program determined the weight at the start of a 10 minute interval. Then it calculated the corresponding best cruise Mach and altitude based on weight. Using the military uninstalled thrust and thrust specific fuel consumption for that Mach and altitude, the program calculated fuel burn for that time interval. With the updated weight, it checked and refueled the aircraft if necessary. Any changes in altitude and weight were instantaneous. Finally, distance travelled was calculated.

The initial weight for the cruise mission was assumed 0.88 W_{TO}. In order to optimize the flight performance, two questions were asked and performance plotted based on weight. First, where could the aircraft fly? This was determined by calculating and graphing the 0 ft/s Ps contour using Equation 1. Second, where should the aircraft fly for maximum range? This corresponding Mach and altitude were determined using Equation 2, assuming L=W, and finding the maximum Range Factor.

Figure 8 shows an example of the system comparisons for the B-1A and B-1Aii at the heaviest cruise weight, W_{init}, both in mil power. The B-1Aii has a much larger available flight envelope shown by the cyan P_s contour. The B-1A does not have enough power to fly supersonic as shown by the red P_s contour. Despite the F119s larger envelope, both planes need to fly at the same Mach and altitude for maximum range at this weight.

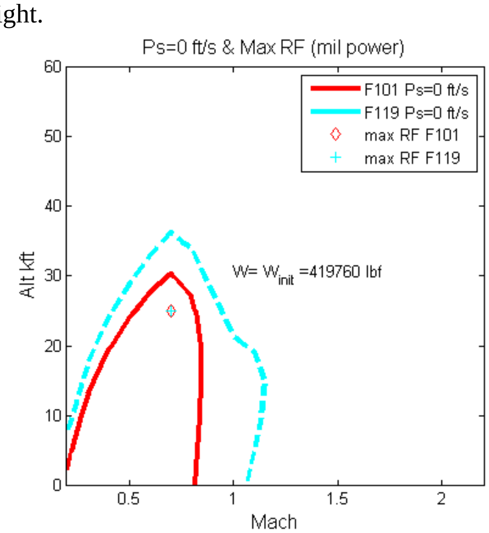

Figure 8. F101 powered B-1A Ps=0 ft/s contour and max range factor flight condition in red compared to the F119 powered B-1Aii in cyan for the initial cruise weight, both in mil power.

Figure 9 shows the opposite extreme, the lightest cruise weight, W_{refuel}, for both configurations in mil power. This figure shows how the two aircraft perform just prior to requiring refuel. Here, the B-1Aii has gained a tremendous advantage in available flight envelope. The B-1A is still unable to fly supersonic in mil power. The altitude for maximum range has increased for both aircraft. The altitude for max range for the B-1A is higher, but its cruise ceiling is still about 5000 ft lower than for the B-1Aii.

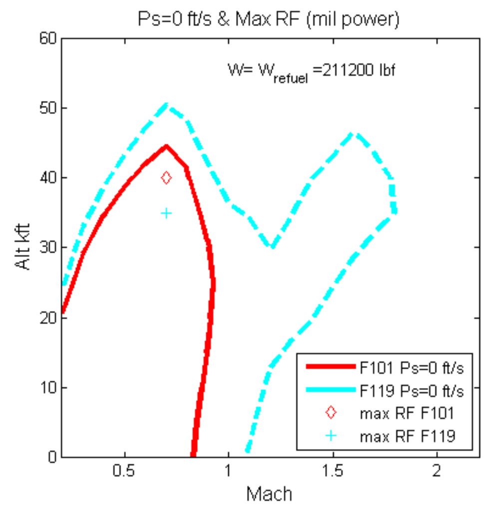

Figure 9. F101 powered B-1A Ps=0 ft/s contour and max range factor flight condition in red compared to the F119 powered B-1Aii in cyan at the minimum weight before refueling, both in mil power.

Equation 1 for the aircraft P_s shows that the aircraft drag polar, weight, planform area, and thrust were needed. The flight condition provided the information for velocity and dynamic pressure. The Mach values were discretized from Mach 0 to 2.2 in increments of 0.1. The altitudes range from 0 to 60 kft in increments of 5 kft. This reduced computational time with minimal loss in resolution. The mil power uninstalled thrust for each engine was used at the discretized Mach and altitude values.

Equation 1. (2)

$$\boxed{P_s = V\left[\frac{T}{W} - \frac{K_1 W}{qS} - \frac{C_{D0} qS}{W}\right]}$$

The Range Factor was calculated using Equation 2. In order to determine the lift to drag ratio, L/D, the current weight, relation between lift coefficient and angle of attack, and drag polar were used. The velocity was part of the discretized flight envelope. The uninstalled mil power SFC at each discrete Mach and altitude was used for each engine.

Equation 2. (2)

$$\boxed{RF = \frac{L}{D}\frac{V}{TSFC}}$$

The program iteration interval, dt, was 10 minutes. After 10 minutes of flight, the program calculated the amount of fuel burned using Equation 3. The most accurate engine performance parameters for Equation 3 are installed, throttle set values. For this effort, uninstalled values are used. These engine performance values depend on the Mach number and altitude. Rather than select a Mach and altitude for cruise, these values were optimized for maximum range at each time interval.

Equation 3. (2) $\boxed{\Delta W = -TSFC \cdot T \cdot dt}$

The distance travelled per time interval was the product of the initial velocity and the time interval. The simplifying assumptions to this point include: 1. a discrete atmosphere, 2. uninstalled mil power thrust and specific fuel consumption at these discrete points and 3. the B-1A empty weight is the same with any engine. The first assumption, discretization, has a small impact on resolution. The second assumption for the engine, however, does not take into account installation losses or the throttle hook. Installation losses will produce lower thrust and greater fuel burn, but likely less than 5% difference on each during cruise. The throttle hook will allow for decreased fuel burn when throttling back to match required thrust for a particular Mach and altitude. This impact could be significant and should be addressed in future efforts. The weight impact of different engines is less than 1% and therefore negligible.

3 RE-ENGINE INVESTIGATIONS

For this exercise, the mission was greatly simplified to only look at cruise starting at Diego Garcia, flying over Baghdad, then Afghanistan, and returning to Diego Garcia. This nearly triangular route ignored take-off and climb and partial throttle performance, but allowed for refueling and Mach and altitude adjustment.

3.1 Cruise at best Range Factor Mach and Altitude

The first investigation simply flew the three aircraft configurations at each of their optimized Range Factor Mach and altitudes. Figure 10 shows a snap shot of the simulation after 13 hours. For each subplot, red corresponds to the B-1A, blue or cyan is for the B-1Aii, and green is for the B-1Aiii.

In the top left subplot, the aircraft weight is tracked over time. Notice that the B-1Aii burns fuel faster. This is because of its lower bypass, higher Tt4 and therefore, higher thrust specific fuel consumption in mil power (no partial throttle setting capability in this current model). Additionally, the altitude for maximum range is plotted as a function of time. This reflects that as the fuel burns for either aircraft, the altitude for max range increases.

The top right subplot shows the weight specific excess power contour that is the extent of the flight envelope for the B-1A and B-1Aii. The max range Mach and altitude for these aircraft at their respective weights is shown.

The bottom left subplot shows the thrust available versus thrust required for that particular aircraft weight and altitude. Additionally, the angle of attack for the aircraft is shown. At this point, the simulation always uses all of the thrust available at the best Mach and altitude point.

The bottom right subplot shows the great circle route race track. Each of the aircraft configurations has its own track. This current image shows that all three configurations are travelling nearly the same distance for this amount of time. This fact is driven by the Mach for maximum range. Even though the B-1Aii and B-1Aiii configurations can supercruise, this advantage is not used in this first simulation.

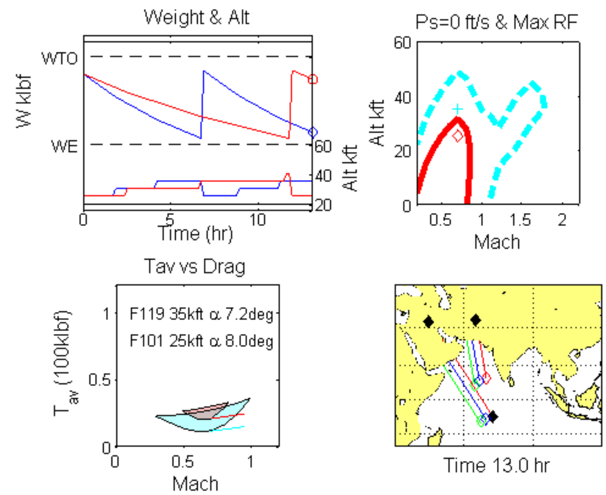

Figure 10. Simulation after 13 hours.

This first investigation was simply to validate that the virtual flight concept could work. It did not take into account the lower fuel burn that would occur using partial throttle settings that would be better suited for the F483 and F119 engines. Even the F101 engines would see some improvement in overall fuel burn if it could take advantage of throttle hook.

The important thing to take away from Figure 10 is that all of the important parameters for cruise investigation can be displayed and tracked in a video. This is powerful as an instructional tool. The effect of fuel burn on the altitude, excess power, angle of attack, and thrust required can be discussed while the video runs. As the aircraft weight decreases, the altitude for max range increases. As the weight decreases, the flight envelope increases. For the F119 this includes increasing supersonic regions. As the fuel burns, the angle of attack can decrease, which lowers the drag and allows for the aircraft to require less thrust.

Even the fact that the engines are held to mil power provides for interesting student investigations. Why does the F119 burn fuel faster than the F101? Because the F119 has a much lower bypass ratio and higher Tt4 than the F101. Why would being able to fly in partial throttle settings help decrease the fuel burn? Because of the larger thrust available. At a partial throttle setting, the aircraft could maintain cruise without burning as much fuel.

Another learning point for the engine designer is the importance of system integration. Even though the more powerful F119s open up the flight envelop, the aircraft drag characteristics still want the plane to fly subsonic for maximum range. That undeniable fact shows how much influence supersonic drag has on overall system performance.

3.2 Supercruise using best available Range Factor

The previous investigation did not take advantage of greater thrust available with F119 engines. Figure 11 shows that as the B-1Aii configuration drops below 373 klbf, a supersonic P_s island opens up. That means the pilot could use afterburners to get to M=1.4 and 25 kft and then supercruise. It also shows that the range factor at this flight condition is about one third of the maximum range factor.

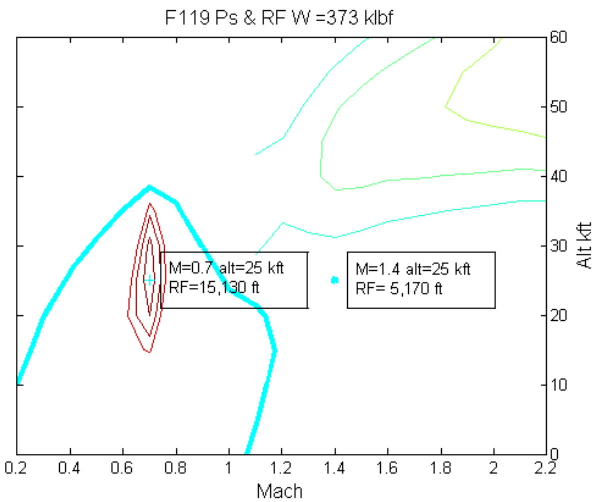

Figure 11. B-1Aii weight specific excess power and Range Factor contours for W=373 klbf.

Now the question becomes, what would happen if the B-1Aii could supercruise at the maximum supersonic range factor flight conditions. Figure 12 shows the result of this investigation. All of the subplots are the same except the bottom left. This subplot now determines the cruise Mach and altitude for the maximum supersonic range factor, designated by the diamond.

The result is that the F119 powered B-1Aii can supercruise for 2 hours without refueling. During this time, it is able to fly more than twice as far as the mil powered B-1A. It flies nearly 1000 nautical miles farther. The B-1Aii can also fly at higher altitudes, over 40 kft, by taking advantage of thrust available. The cost for this performance is about 125 klbf during this supercruise leg compared to the fuel burned by the B-1A.

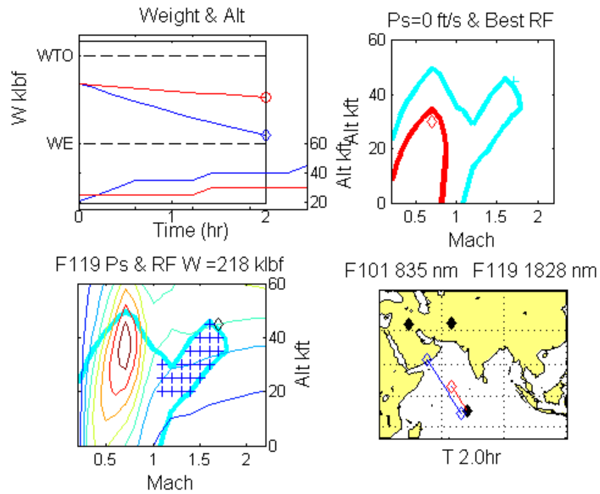

Figure 12. Supercruise simulation.

Although the same assumption of mil power applies, this is a fairly realistic performance estimate. This is because for both aircraft configurations, the engines at these corresponding cruise Mach and altitudes will be very nearly at full throttle. The advantage of the virtual fly component is that mission effects can be shown directly on the map.

4 CONCLUSIONS AND RECOMMENDATIONS

This simulation was a first order effort to allow cadets in the engine capstone to virtually fly their design. Additionally, it demonstrated key attributes of software design methodology:

1. Modular design
2. Process for modeling, verifying, and comparing
3. Tracking assumptions and impact

The resulting video proved a powerful demonstration tool incorporating an understanding of system level impacts. The limiting effect of supersonic drag kept the cruise leg optimized at subsonic flight conditions despite wing sweep and the supercruise capable F119. Without the advantage of throttling back, the first investigation of max cruise did not provide reasonable numbers for fuel burn and distance travelled. However, the full throttle assumption for the supercruise mission B-1Aii showed the altitude and range advantages possible with F119 engines.

The next course of action is to improve simulation fidelity. First, using installed values for thrust and TSFC will decrease the overall distance travelled and increase fuel burn for a particular throttle setting. The larger impact on fidelity will come from incorporating throttle hook into the simulation. By allowing partial settings the engines will be able to accurately produce lower levels of thrust, thereby decreasing overall fuel burn. The next version will be a better predictor of performance, but still keep cadets excited about seeing their engine fly.

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