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AXISYMMETRIC APPROACH AND LANDING THRUST REVERSER IMPACTS ON USAGE AND LCC

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Abstract

A study has been made of the effects of an approach and landing thrust reverser (ALTR) on engine usage and aircraft Life Cycle Cost (LCC). This study considered two tactical fighter aircraft and three thrust reverser types.

Reference usages were established for a current fighter aircraft without ALTR from recorded field data. For this aircraft, the performance changes and the differences in landing procedures occasioned when the ALTRs were installed caused increases in engine hot time and in cyclic usage. These increases which were similar for both ALTR concepts amounted to approximately 16% in hot time, 1% in Type I cycles and 17% in Type III cycles. Engine hot time is defined here as time spent at or above 95% maximum engine speed. Cyclic usage is described by two types of cycle, the engine off to max power to off cycle (Type I) and the idle power to max power to idle power cycle (Type III). Reference usages were also predicted for an advanced tactical aircraft without ALTR from previously established techniques and models. The aircraft was then resized with an ALTR to meet minimum mission requirements and the changes in usage identified. The results showed a 13% increase in hot time, 1% increase in Type I cycles and 18% increase in Type III cycles.

The LCC for the baseline current and advanced aircraft with and without ALTR were estimated using the McAir Advanced Concepts Cost Model (ACCM), and a consistent set of ground rules. For the current aircraft, increases in overall LCC with ALTR were of the order of 3%. For the advanced aircraft, the LCC of the aircraft with ALTR were approximately 1% less than the aircraft without ALTR.

Introduction

Engine thrust reversers can provide a substantial improvement in aircraft landing performance in terms of runway length requirements and independence from runway surface conditions. Thrust reversers which deploy after aircraft touch-down are already operational on two European tactical aircraft and they have also been used to advantage on many civilian transports. However, the attainment of full reverse thrust on the ground is delayed by the reverser deployment and engine acceleration times. These delays occur at the highest landing speeds resulting in additional ground roll which could be eliminated if the engine was set at maximum speed on approach and the excess thrust spoiled by partial deployment of the thrust reverser.

The Axisymmetric Nozzle Approach and Landing Thrust Reverser (ALTR) program, sponsored by the USAF, is studying the effects on tactical aircraft of engine thrust reversers which can be deployed on aircraft final approach. This program is being conducted by McDonnell Douglas Aircraft Company with Pratt and Whitney Aircraft Company as the main subcontractor.

The effects of ALTR on aircraft aerodynamic, mission and field performance have been presented previously (Reference 1). However, besides the operational advantages and disadvantages of an ALTR there are other factors which might mitigate against their use. One very important factor in any weapon system procurement is the total projected cost of that system over its useful life. With aircraft weapon system Life Cycle Costs (LCC) in the tens of billions of dollars, even small percentages mean large absolute numbers. Therefore, a careful evaluation of the impacts on system LCC should be an essential part of any study such as this.

Studies (References 2 and 3) have shown that engine related costs make up approximately 40-50% of a typical tactical fighter's total LCC. An important portion of this cost is related to the way the engine is used operationally. The definition of the engine duty cycle thus becomes a vital part of the design process if performance and cost are to be properly balanced.

This paper reports the impacts of the installation of ALTRs on engine usage and on the total weapon system LCC. The study considered two aircraft types: (a) a current high performance fighter and (b) an advanced tactical fighter aircraft designed for IOC in mid 1990's. The F15-C aircraft, Figure 1, was selected as the current fighter; the basic airframe, engine and mission performance characteristics are well defined from flight and ground test data. The advanced aircraft, Figure 2, is an air-to-surface (ATS) vehicle designed for a long range high altitude supersonic strike mission to deliver weapons from standoff range. A mission was postulated with a 350 nm subsonic cruise and a 200 nm supersonic (M=2.2) dash at high altitude. Typical levels of maneuver requirements were also established for self defense. Additionally, this aircraft has a requirement to take-off and land within a field length of 1300 feet on a dry runway. The current aircraft provided estimates of ALTR impacts on LCC and engine usage for a fixed size aircraft with different mission and landing performance; while the ATS aircraft showed the ALTR impacts on aircraft size for systems designed for equal mission and airfield performance. Three ALTR concepts were studied: two were installed on the current aircraft, the Rotating Vane ALTR (Figure 3) was installed upstream of the nozzle throat, and the Translating Shroud ALTR (Figure 4) was downstream; the third concept, the 3-Door ALTR (Figure 5) was installed on the advanced aircraft downstream of the nozzle throat.

BASELINE F-15C CONFIGURATION

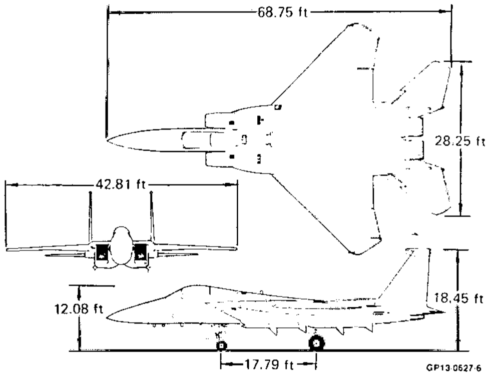

Figure 1

BASELINE AIR-TO-SURFACE (ATS) CONFIGURATION

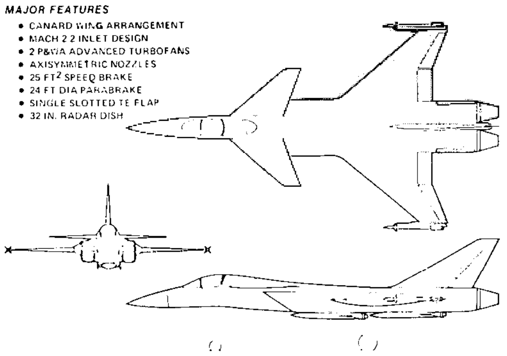

Figure 2

UPSTREAM CLAMSHELL WITH ROTATING VANE ALTR CONCEPT

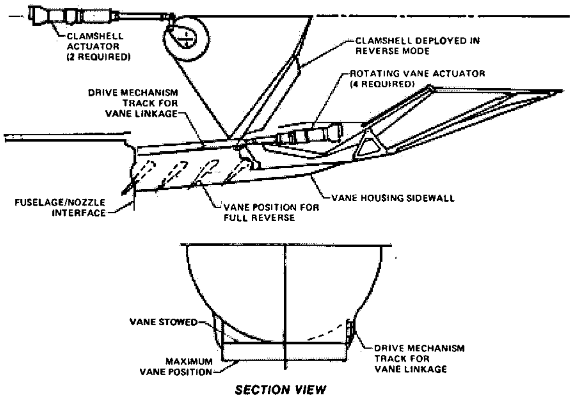

Figure 3

DOWNSTREAM TRANSLATING SHROUD WITH BLOCKER/VANE ALTR CONCEPT

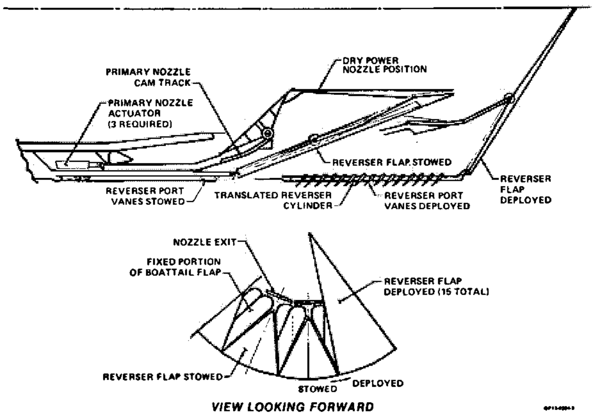

Figure 4

DOWNSTREAM DIVERGENT FLAP BLOCKER ALTR CONCEPT

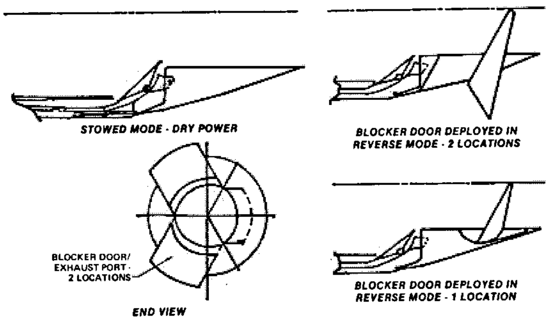

Figure 5

Engine Usage

The way in which the engine is used over a particular mission profile and the profile itself have a profound effect upon engine life consumption rate. Typically engine life has been quoted in terms of flight hours or total engine run time. However, life may be more appropriately defined in terms of specific damaging events. The primary causes of failures for life limited engine parts are stress rupture, creep, oxidation and erosion and low cycle fatigue (LCF). Stress rupture, creep, oxidation and erosion occur in the hot section of the engine, particularly the turbine airfoils, and are dependent principally on the amount of time spent at or near the maximum operating temperature. LCF, on the other hand, may occur in any component subjected to thermal or mechanical cyclic stresses. LCF is dependent upon the number and severity of stress cycles to which the component is subjected.

In this paper, engine usage is described by 3 parameters; these are hot time, i.e. time spent at or above 95% maximum engine rpm, the number of full throttle cycles from engine start-up to intermediate power and back to engine shut-down (Type I), and the number of throttle transients from idle power to intermediate and back to idle (Type III). The McAir Engine Usage Prediction Model (Reference 4), developed under a previous USAF program and Independent Research and Development (IRAD) studies was used here to establish the changes in usage associated with the installation of the ALTRs. This model (Figure 6) separates engine usage into ground and flight operations, including steady-state segments, e.g. take-off, cruise and descent, and dynamic segments, e.g. air-to-air combat, air-to-ground bombing and terrain following. The steady-state segments require only aircraft aerodynamics and engine thrust; however the dynamic segments require steady-state characteristics, engine dynamics and pilot tactics modeling. In this study, the F100 engine performance was computed using the Pratt and Whitney customer deck and the performance for the engine in the ATS aircraft was computed using the P&W Parametric Cycle deck.

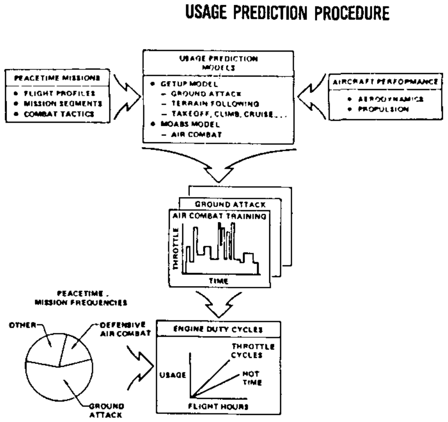

Figure 6

Current Aircraft

Baseline Usage. Peacetime deployment of tactical fighters results in a variety of engine usages for a particular mission type. For this study, field data from two USAF bases were used; these were (a) an operational training base with a severe engine usage requirement resulting from the close proximity to training ranges, (b) a transitional training base with a larger number of aircraft but less severe engine usage.

The spectrum of peacetime mission types and frequencies at both bases developed by McAir under a previous IRAD program is shown at Figure 7. A mission mix between the operational and training base was defined from product support data to be about 70%/30%. Mission durations are shown in terms of ground and flight time. The ground time represents pre-flight engine start and warm-up, avionics warm-up and checks, weapons arming and checks and time spent taxiing and awaiting take-off clearance. The McAir model was used to predict the engine usage in terms of hot time and throttle cycles accumulated for the mission mix shown at Figure 7. The results are presented at Figure 8 for each mission type and for 2000 hours of total engine run time. Representative ground test stand maintenance operation was included consistent with that provided in Reference 5. The total predicted usage of 189 hours hot time, 950 Type I cycles and 6908 Type III cycles over 2000 engine run hours agrees well with actual field data. (Reference 6).

BASELINE F-15C USAGE MISSION SUMMARY

MISSION TYPE	FREQUENCY AT OPERATING BASE (%)	FREQUENCY AT TRAINING BASE (%)	COMBINED FREQUENCY (%)	AVERAGE MISSION DURATION (HR)	
				GROUND	FLIGHT
BASIC FIGHTER MANEUVERS	23	27	24	0.90	0.98
AIR COMBAT TACTICS	37	15	31	0.90	0.90
DISSIMILAR AIR COMBAT, TACTICS	22	16	20	0.90	1.18
INTERCEPT TRAINING	10	16	12	0.90	2.71
AIR-TO-AIR GUNNERY	5	5	5	0.90	1.34
TRANSITIONAL TRAINING	—	18	5	0.82	1.66
FUNCTIONAL CHECK FLIGHT	2	2	2	0.90	1.22
FERRY/CROSS COUNTRY	1	1	1	0.90	2.45

Figure 7

BASELINE F-15C ENGINE USAGE SUMMARY

MISSION TYPE	MISSION FREQUENCY	MISSION DURATION (HR)	PER MISSION			2 000 TOTAL ENGINE RUN HRS		
			HOT TIME (MIN)	TYPE I CYCLES	TYPE III CYCLES	HOT TIME (HR)	TYPE I CYCLES	TYPE III CYCLES
BASIC FIGHTER MANEUVERS	0.24	1.86	12.3	1	7	44.9	219	1 533
AIR COMBAT TACTICS	0.31	1.80	12.7	1	6	59.9	283	1 697
DISSIMILAR AIR COMBAT	0.20	2.08	12.8	1	9	38.9	182	1 642
INTERCEPT TRAINING	0.12	3.61	10.1	1	4.8	18.4	109	526
AIR/AIR GUNNERY	0.05	2.24	7.6	1	13	5.8	46	593
TRANSITIONAL TRAINING	0.05	2.48	8.6	1	14.5	6.6	46	662
FUNCTIONAL CHECK FLIGHT	0.02	1.12	17.4	2	3	5.3	36	55
FERRY CROSS-COUNTRY	0.01	3.35	2.9	1	0	0.4	9	0
MAINTENANCE	—	1.20	28.0	1	10	9.2	20	200
					TOTAL	189.3	950	6 908

Notes
(1) Type I Cycle Engine off to intermediate to off
(2) Type III Cycle Idle to intermediate to idle

Figure 8

ALTR Deployment. The simulation of the aircraft landing sequence with ALTR for this evaluation is shown schematically at Figure 9. The ALTR is partially deployed and the throttle set at intermediate power as the aircraft is in its final turn with the airspeed at 200 knots. This airspeed is the maximum for ALTR deployment specified in the design criteria and therefore represents the worst case in terms of impact on engine usage.

ALTR Equipped Engine Usage. Engine usage for an F-15C equipped with approach and landing thrust reversers was predicted for two ALTR designs, the Translating Shroud (T/S) and the Rotating Vane (R/V) ALTRs. The most significant difference between these designs is that the reverser ports are upstream of the primary nozzle throat on the R/V ALTR and downstream on the T/S. Both reversers add considerable weight to the aircraft, but the R/V ALTR is about twice as heavy as the T/S.

ALTR LANDING SIMULATION FOR ENGINE USAGE EVALUATION

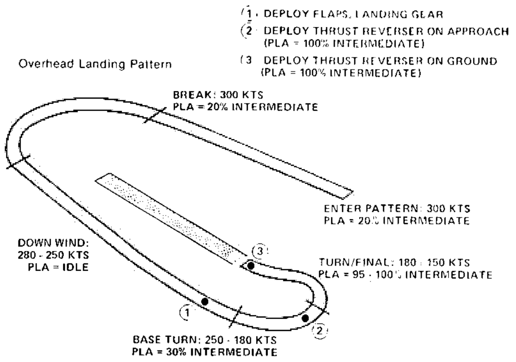

Figure 9

Translating Shroud ALTR. The results of the engine usage prediction for the F-15C with the T/S ALTR are shown in Figure 10 for each mission, and for a 2000 total engine run hour summary. The increased engine hot time reflects ALTR deployment on approach, starting at an airspeed of 200 knots, for every landing. When compared to the baseline F-15C engine usage, the hot time is increased 15.8%, Type I cycles increased 0.7%, and Type III cycles increased 17% with ALTR usage.

F-15C ENGINE USAGE SUMMARY WITH T/S ALTR

			PER MISSION			2,000 TOTAL ENGINE RUN HOURS		
MISSION TYPE	MISSION FREQUENCY	MISSION DURATION (HR)	HOT TIME (MIN)	TYPE I CYCLES	TYPE III CYCLES	HOT TIME (HR)	TYPE I CYCLES	TYPE III CYCLES
BASIC FIGHTER MANEUVERS	0.24	1.82	14.1	1	8	51.8	220	1,763
AIR COMBAT TACTICS	0.31	1.84	13.9	1	8	65.9	285	2,277
DISSIMILAR AIR COMBAT	0.20	2.00	15.4	1	9	47.1	184	1,653
INTERCEPT TRAINING	0.12	3.60	11.5	1	6.8	21.1	110	749
AIR/AIR GUNNERY	0.05	2.24	9.6	1	14	7.3	46	643
TRANSITIONAL TRAINING	0.05	2.49	13.5	1	15.5	10.3	46	712
FUNCTIONAL CHECK FLIGHT	0.02	2.13	19.6	2	4	6.0	37	73
FERRY CROSS-COUNTRY	0.01	3.36	4.2	1	1	0.6	9	9
MAINTENANCE	—	1.20	28.0	1	10	9.2	20	200
					TOTAL	219.3	957	8,079

Notes
(1) Type I Cycle: Engine off to intermediate to off
(2) Type III Cycle: Idle to intermediate to idle

Figure 10

Virtually all of these increases were due to the deployment of the ALTR although some resulted from performance changes described at Reference 1. In particular, the performance changes due to ALTR caused an extra Type III cycle during a maneuver in the intercept training mission when the throttle was momentarily set at idle. This represents only a few degrees change in PLA from the baseline F-15C, however, due to the definition of Type III cycles, an extra cycle was counted.

The increase in hot time reflects the additional time spent at intermediate power when the ALTR is deployed on the landing approach. The greatest increase in hot time occurred on the transitional training mission, which simulated several touch-and-go landings prior to final landing. For that mission, hot time increased 57% with the T/S ALTR.

The small increase in Type I cycles was caused by the slightly reduced mission length. This resulted from the increased fuel consumption rate with the ALTR installed caused by increased weight and subsonic drag.

An extra Type III throttle cycle was obtained on each mission during the landing segment, when the throttle was increased to intermediate power.

The impact on engine usage of the frequency at which the ALTR is used on the approach rather than after touchdown was also examined. The results, summarized in Figure 11 show that infrequent usage of the ALTR on approach reduces the engine hot time. Throttle cycles remain the same. The hot time is reduced 12.4% if the ALTR is used only after touchdown. This represents a 1.4% increase over the baseline F-15C hot time.

IMPACT OF ALTR APPROACH DEPLOYMENT FREQUENCY ON ENGINE HOT TIME FOR T/S ALTR F-15

- 2,000 ENGINE RUN HOURS

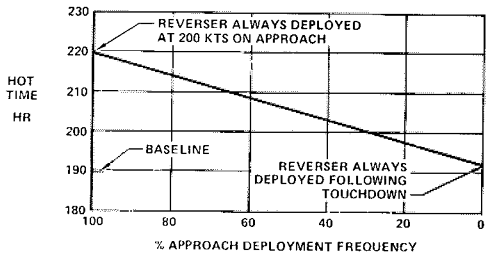

Figure 11

Rotating Vane ALTR. The impact of the R/V ALTR on the F-15C engine usage was determined in the same manner as for the T/S ALTR. The engine usage results with the R/V ALTR installed are summarized in Figure 12. When compared to the baseline F-15C 2000 hour engine usage summary, the use of an R/V ALTR increases hot time by 13.8%, Type I cycles by 1%, and Type III cycles by 19%. These increases are comparable to those shown for the T/S ALTR installation. The slight differences are due primarily to the variations in aircraft performance and weight caused by the different ALTR installations.

R/V ALTR deployment only after touchdown yielded 188 hours of hot time over 2000 engine run hours, a 13% decrease from the case in which it is used on the approach. This also represents a 1% decrease from the baseline F-15C, because the reduced mission duration caused by performance decrements when ALTR is installed more than offsets the additional hot time required for landing reverser deployment.

F-15C ENGINE USAGE SUMMARY WITH R/V ALTR

MISSION TYPE	MISSION DURATION (HR)	PER MISSION HOT TIME (MIN)	PER MISSION TYPE I CYCLES	PER MISSION TYPE III CYCLES	2,000 TOTAL ENGINE RUN HOURS HOT TIME (HR)	2,000 TOTAL ENGINE RUN HOURS TYPE I CYCLES	2,000 TOTAL ENGINE RUN HOURS TYPE III CYCLES
BASIC FIGHTER MANEUVERS	1.82	12.5	1	9	46.1	221	1,990
AIR COMBAT TACTICS	1.82	13.1	1	7	62.4	286	1,999
DISSIMILAR AIR COMBAT	2.01	16.4	1	10	50.4	184	1,843
INTERCEPT TRAINING	3.61	11.8	1	6.8	21.7	111	752
AIR/AIR GUNNERY	2.25	9.9	1	14	7.6	46	645
TRANSITIONAL TRAINING	2.48	14.3	1	15.5	11.0	46	714
FUNCTIONAL CHECK FLIGHT	2.12	20.5	2	4	6.3	37	74
FERRY CROSS-COUNTRY	3.36	4.3	1	1	0.7	9	9
MAINTENANCE	1.20	28.0	1	10	9.2	20	200
				TOTAL	215.4	960	8,226

Figure 12

Advanced Aircraft

A major difference in philosophy was adopted for the advanced aircraft portion of this study compared with that used for the current aircraft. The F-15C study was predicated for fixed aircraft size to reduce the landing ground roll. For the ATS aircraft, however, the ground roll and mission performance were specified and two aircraft were designed to meet these requirements one with and the other without a thrust reverser.

Baseline Usage. The peacetime mission syllabus used for this configuration was developed from a review of peacetime training missions for existing strike aircraft and a projection of the training requirements associated with advanced avionics and weapons systems. The frequency at which each mission profile would be flown was also developed in this manner. A summary of the baseline ATS missions and frequencies used in the usage evaluation is provided in Figure 13. A combined mission frequency was also defined assuming a 70%/30% mix between operational and training base usage.

BASELINE ATS USAGE MISSION SUMMARY

MISSION TYPE (3)	FREQUENCY AT OPERATING BASE (%)	FREQUENCY AT TRAINING BASE (%)	COMBINED FREQUENCY(1) (%)	AVERAGE MISSION DURATION (HR) GROUND(2)	AVERAGE MISSION DURATION (HR) FLIGHT
HIGH ALTITUDE GROUND ATTACK	21	18	20	0.67	1.12
LOW ALTITUDE GROUND ATTACK	25	43	30	0.67	1.08
DEFENSIVE AIR COMBAT TRAINING	20	13	18	0.67	1.13
INSTRUMENT/PROFICIENCY					
— WITHOUT REFUELING	21	—	15	0.67	1.54
— WITH REFUELING	10	—	7	0.67	1.86
TRANSITIONAL TRAINING	—	23	7	0.67	1.58
FUNCTIONAL CHECK FLIGHT	2	2	2	0.67	1.24
FERRY/CROSS COUNTRY	1	1	1	0.67	2.45

Figure 13

Pre and post-flight ground operations for the ATS aircraft were projected to take 40 minutes. This reduced time (from the F-15C) is directly due to projected avionics improvements, which are expected to significantly reduce the time required for warm-up and alignment.

The results of the baseline ATS engine usage prediction are presented in Figure 14. As with the F-15C usage, frequency, mission times, hot time, and throttle cycles accumulated over each mission, and over 2000 engine run hours are identified. The ground test stand maintenance is consistent with that projected for advanced engines as outlined in Reference 5. The hot time (170 hours), Type I cycles (1056), and Type III cycles (10741) are in agreement with those predicted for similar McAir advanced air-to-surface configurations.

BASELINE ATS ENGINE USAGE SUMMARY

MISSION TYPE	MISSION FREQUENCY	MISSION DURATION (HR)	PER MISSION HOT TIME (MIN)	PER MISSION TYPE I CYCLES	PER MISSION TYPE III CYCLES	2,000 TOTAL ENGINE RUN HOURS HOT TIME (HR)	2,000 TOTAL ENGINE RUN HOURS TYPE I CYCLES	2,000 TOTAL ENGINE RUN HOURS TYPE III CYCLES
HIGH ALTITUDE GROUND ATTACK	0.20	1.79	25.4	1	6	86.5	204	1,276
LOW ALTITUDE GROUND ATTACK	0.30	1.75	2.3	1	17	11.7	305	5,209
DEFENSIVE AIR COMBAT	0.18	1.80	15.8	1	8	48.4	184	1,471
INSTRUMENT PROF WITH REFUEL	0.15	2.21	1.9	1	6	4.9	153	919
INSTRUMENT PROF WITHOUT REFUEL	0.07	2.53	3.3	1	11	3.9	71	786
TRANSITIONAL TRAINING	0.07	2.25	6.1	1	14.5	7.3	71	1,037
FUNCTIONAL CHECK FLIGHT	0.02	1.91	15.5	2	3	5.3	41	61
FERRY CROSS-COUNTRY	0.01	3.12	1.6	1	0	0.3	10	0
MAINTENANCE	—	1.00	6.0	1	2	1.6	16	32
					TOTAL	169.9	1,056	10,741

Notes

(1) Type I Cycle. Engine off to intermediate to off

(2) Type III Cycle Idle to intermediate to idle

Figure 14

ALTR Equipped Engine Usage. The impact of the 3-door ALTR on the engine usage for the ATS configuration was assessed in the same manner as for the ALTR-equipped F-15 configurations. When subsequently compared to the baseline usage, the engine usage for this configuration reflects not only ALTR utilization effects, but aircraft size, performance, and available fuel differences. This ALTR-equipped ATS configuration, sized to meet the same mission and landing ground roll, is 10% lighter with 13% less internal fuel and 65% higher takeoff wing loading. All of these differences impact how the system is used in the various missions, especially the air combat training. The peacetime mission syllabus for this configuration was assumed the same as for the baseline ATS configuration.

The engine usage results for this configuration are summarized in Figure 15. The hot time (193 hours), Type I cycles (1065), and Type III cycles (12647) over 2000 engine run hours represent increases of 13%, 1% and 18% respectively over the baseline ATS configuration. These results assume the ALTR is used on every landing.

Those missions that involve several touch-and-go landings show a marked increase in hot time with the 3-door ALTR. Specifically, the instrument proficiency (with and without refueling) and transitional training missions show a combined 300% increase in hot time. The fuel limited Defensive Air Combat Training mission, however, has less hot time than the baseline configuration due primarily to fewer combat engagements caused by 17% less available combat fuel. The majority of this was due to less internal fuel capacity for this aircraft.

ENGINE USAGE SUMMARY FOR ATS WITH 3-DOOR ALTR

			PER MISSION			2,000 TOTAL ENGINE RUN HOURS		
MISSION TYPE	MISSION FREQ	MISSION DURATION (HR)	HOT TIME (MIN)	TYPE I CYCLES	TYPE III CYCLES	HOT TIME (HR)	TYPE I CYCLES	TYPE III CYCLES
HIGH ALTITUDE GROUND ATTACK	0.20	1.81	24.3	1	7	83.4	206	1,442
LOW ALTITUDE GROUND ATTACK	0.30	1.74	3.7	1	19	19.1	309	5,870
DEFENSIVE AIR COMBAT	0.18	1.70	13.2	1	11	40.8	185	2,039
INSTRUMENT PROF W/ REFUEL	0.15	2.21	7.1	1	7	18.3	154	1,081
INSTRUMENT PROF W/O REFUEL	0.07	2.54	8.3	1	12	10.0	72	865
TRANSTIONAL TRAINING	0.07	2.25	11.9	1	17	14.3	72	1,226
FUNCTIONAL CHECK FLIGHT	0.02	1.92	14.0	2	4	4.8	41	82
FERRY CROSS-COUNTRY	0.01	3.12	3.0	1	1	0.5	10	10
MAINTENANCE	–	1.00	6.0	1	2	1.6	16	32
					TOTAL	192.8	1,065	12,647

Notes:

(1) Type I Cycle: Engine off to intermediate to off

(2) Type III Cycle: Idle to intermediate to idle

Figure 15

The increase in Type III cycles (18%) over the baseline ATS was due to two factors. First, the extra cycle needed to spool the engine up during the landing approach on each mission accounted for about 55% of the increase. The remaining increase was due to the changes in aircraft combat performance characteristics as evaluated in the McAir air combat simulation model.

The impact of deploying the ALTR only after touchdown was also investigated. Although the Type I and Type III cycles remain the same, the hot time is decreased 11% from the baseline. The majority of this decrease is due to the reduced combat training hot time caused by less available fuel, which is not offset by significant hot time increases during landing.

Summary of Usage Effects. A summary of the effects of ALTR installation on engine usage is presented at Figure 16. Clearly the ALTRs have a major impact on engine usage over 2000 engine run hours. Average increases for the 3 ALTR concepts are 14.2% in hot time, 1% in Type I cycles and 18% in Type III cycles. However, the differences in percentage terms between the 3 ALTR concepts is small, 2.8% hot time, 0.3% Type I cycles, 2% Type III cycles. This is true even when the ALTR is incorporated at the aircraft design stage. When the reversers are used only as ground thrust reversers the cyclic content remains the same as when used on approach. However the hot time is substantially different. The T/S and R/V produce hot times which are within 2% of the F-15C without ALTR; but the ATS with the 3-door ALTR requires 11% less hot time than the ATS baseline due primarily to the reduced internal fuel capacity of this aircraft.

SUMMARY
ALTR IMPACT ON ENGINE USAGE
DELTA % FROM BASELINE

	ALTR			GROUND TR		
	T/S	R/V	3-DOOR	T/S	R/V	3-DOOR
TAT	15.8	13.8	13	1.4	-1.0	-11
TYPE I	0.7	1	1	.7	1.0	1.0
TYPE III	17	19	18	17	19	18

TAT - TIME AT TEMPERATURE

Figure 16

Conclusions on ALTR Equipped Aircraft Engine Usage. Future tactical aircraft equipped with approach and landing thrust reversers will require on average, 15% more hot time and 17% more Type III throttle cycles than conventional nozzle equipped aircraft. Engine designers must take into account this more severe usage when establishing the structural design criteria for engines that will be equipped with approach and landing thrust reversers. Failure to do so may result in engines with significantly shorter service lives than expected.

Aircraft Life Cycle Cost

All LCC figures generated in this study were derived from the McAir Advanced Concepts Cost Model (ACCM) (Figure 17). This model provides the capability to generate LCC estimates for advanced aircraft design configurations by addressing aircraft and subsystem costs in three categories, Research Development Test and Evaluation (RDT&E), production, and operating & support (O&S) costs.

MCAIR ADVANCED CONCEPTS COST MODEL

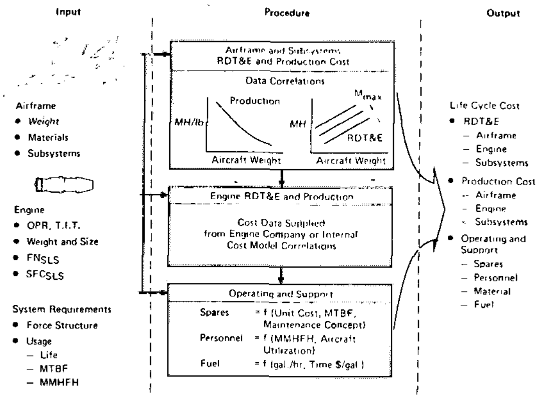

Figure 17

The airframe and subsystem RDT&E and production costs are based on an extensive McAir historical data base of previously developed fighters. The F15 and F100(3) cost data are part of this historical base. Cost estimating relationships were developed using documented cost data. The engine associated costs were supplied by P&WA. Ground rules (Figure 18) were established for this LCC evlauation which were applicable to both the F15C and the ATS configuration. These provided a consistent basis for subsequently evaluating the impacts of the ALTR installation the aircraft LCC.

AIRCRAFT LCC EVALUATION GROUND RULES

DOLLARS	FY 1980	
LIFE CYCLE PERIOD, YEARS PER AIRCRAFT	15	
NUMBER OF OPERATIONAL AIRCRAFT	648 (24 AIRCRAFT PER SQUADRON, 3 SQUADRONS PER BASE, 9 BASES)	
FLIGHT HOURS PER YEAR - OPERATIONAL AIRCRAFT	300	
TOTAL FLIGHT HOURS - MILLIONS	2.916	
NUMBER OF PIPELINE SPARE AIRCRAFT	65 (10% OF OPERATIONAL AIRCRAFT)	
NUMBER OF AIRCRAFT ATTRITED DURING LIFE CYCLE	175 (6/100,000 FLIGHT HOURS)	
TOTAL NUMBER OF AIRCRAFT PRODUCED	888*	
MAXIMUM AIRCRAFT PRODUCTION RATE - AIRCRAFT PER MONTH	10	
NUMBER OF SPARE ENGINES	259 (20% OF OPERATIONAL ENGINES)	
TOTAL NUMBER OF ENGINES PRODUCED	2,035	
NUMBER OF FLIGHT TEST AIRCRAFT	12	N/A FOR F-15C
NUMBER OF FLIGHT TEST ENGINES - INCLUDING SPARES	36	
BASELINE FUEL COST - DOLLARS PER GALLON	$1.80	

*For the F-15C, the 888 aircraft produced are assumed to come after the current buy of 729 aircraft.

Figure 18

Current Aircraft

Baseline LCC. Three notes are necessary on the ground rules as applied to the F-15C. Firstly, the 888 aircraft produced were assumed to come after the current planned AF buy of 729 aircraft; secondly the flight test aircraft and associated engines were not considered necessary for the F-15C as flight test vehicles are already available and would only require modification to accept the ALTRs. Finally, no research and development costs for the baseline F15-C have been included in this evaluation.

To compute fuel costs over the aircraft life cycle, the engine usage prediction results were used to estimate the total engine run time per aircraft flight hours, and the average fuel consumption per engine run hour. From the F-15C usage results, 300 aircraft flight hours per year (from the LCC groundrules) would result in an additional 210 ground hours for a total of 510 engine run hours per year. The average fuel consumption per engine run hour was estimated as 1818 gallons/hour for in-flight operation and 350 gallons/hour for ground operation.

The results of the baseline F-15C life cycle cost analysis are broken down by major elements in Figure 19. The contribution of each element is normalized with respect to the total LCC.

BASELINE F-15C LCC SUMMARY

LCC ELEMENT	CONTRIBUTION
* RDT&E	0
* INVESTMENT	0.392
-AIRFRAME	0.135
-ENGINE PRODUCTION	0.094
-AVIONICS	0.065
-SUBSYSTEMS	0.026
-ENGINE CIP	0.022
-OTHER	0.051
* O&S	0.608
-FUEL	0.295
-ENGINE MAINTENANCE	0.073
-OTHER MAINTENANCE	0.077
-OTHER	0.163
TOTAL:	1.000

Figure 19

T/S Equipped LCC. The impact of the T/S ALTR on the F-15C life cycle cost was evaluated using the same LCC procedures as for the baseline configuration, discussed above. The primary LCC elements that would be affected by incorporation of an ALTR include (1) airframe production cost, (2) engine production cost, (3) engine component improvement cost, (4) engine maintenance cost, and (5) fuel cost. Based on the T/S ALTR conceptual design layout, the F100(3) engine-related LCC changes were estimated as follows:

o % Change in Engine Production Cost = +7.4

o % Change in Engine Maintenance Cost = +1.8

o % Change in Engine CIP Cost = +7.4

The engine usage results for this configuration were used to estimate the average fuel consumption per engine run hour, which were 1880 gallons/hour for in-flight operation and 350 gallons/hour for ground operation. The relationship between the ground time and flight time for this configuration, as also determined from the engine usage results, was virtually the same as for the baseline F-15C vehicle.

These estimates were input to the McAir ACCM to assess the overall LCC of the T/S ALTR-equipped F-15C, consistent with the previous groundrules. The LCC estimates for this vehicle are compared to the baseline in Figure 20. The overall LCC for the T/S ALTR F-15 was estimated to be 2.3% greater than for the baseline F-15C. The primary contributors are the engine production cost and fuel cost, accounting for about 67% of the increase.

R/V Equipped LCC. The impact of the R/V ALTR on the F-15C life cycle cost was evaluated in the same manner as for F-15C with T/S ALTR. Based on the R/V ALTR preliminary design layout, the F100(3) engine-related LCC changes were estimated as follows:

o % Change in Engine Production Cost = +8.3

o % Change in Engine Maintenance Cost = +3.1

- o % Change in Engine CIP Cost = +8.3

The engine usage results for this configuration were used to estimate the average fuel consumption per engine run hour, which were 1945 gallons/hour for in-flight operation and 350 gallons/hour for ground operation. The relationship between the ground time and flight time for this configuration was also virtually the same as for the baseline F-15C configuration.

T/S ALTR IMPACT ON F-15C LCC

LCC ELEMENT	BASELINE F-15C	F-15 WITH T/S ALTR	LCC \$M
* RDT&E	0	0.002	+80
-AIRFRAME	0	0.001	+50
-ENGINE/NOZZLE	0	0.001	+30
* INVESTMENT	0.392	0.402	+378
-AIRFRAME (INCLUDING SPARES)	0.135	0.137	+75
-ENGINE (INCLUDING SPARES)	0.094	0.101	+254
-AVIONICS (INCLUDING SPARES)	0.065	0.065	0
-SUBSYSTEMS	0.026	0.026	-5
-ENGINE CIP	0.022	0.022	+10
-OTHER	0.051	0.051	+44
* O&S	0.608	0.619	+381
-FUEL	0.295	0.305	+326
-ENGINE MAINTENANCE	0.073	0.074	+48
-OTHER MAINTENANCE	0.077	0.077	0
-OTHER	0.163	0.163	+7
TOTAL	1.000	1.023	+839

Figure 20

The above information was input to the McAir ACCM to assess the overall LCC of this configuration. The LCC estimates are compared to the baseline in Figure 21. The overall LCC for the R/V ALTR F-15C was estimated to be 3.8% greater than for the baseline F-15C. As with the T/S ALTR-equipped the primary contributors to the LCC increase are the engine production cost and fuel cost, accounting for about 70% of the increase.

R/V ALTR IMPACT ON F-15C LCC

LCC ELEMENT	BASELINE F-15C	F-15 WITH R/V ALTR	LCC SM
* RDT&E	0	0.004	+126
-AIRFRAME	0	0.003	+91
-ENGINE/NOZZLE	0	0.001	+35
* INVESTMENT	0.392	0.406	+483
-AIRFRAME	0.135	0.139	+131
-ENGINE PRODUCTION	0.094	0.102	+285
-AVIONICS	0.065	0.065	0
-SUBSYSTEMS	0.026	0.026	-5
-ENGINE CIP	0.022	0.023	+20
-OTHER	0.051	0.051	+52
* O&S	0.608	0.628	+758
-FUEL	0.295	0.313	+667
-ENGINE MAINTENANCE	0.073	0.075	+83
-OTHER MAINTENANCE	0.077	0.077	0
-OTHER	0.163	0.163	+8
TOTAL	1.000	1.038	+1.367

Figure 21

Brake Savings. The study reported in Reference 7 indicated that a potentially significant reduction in F-15C brake wear, and associated life cycle cost savings, might be realized if an ALTR was available to control the ground taxi speeds. In the current study, this was examined further.

The incorporation of an ALTR allows full authority over taxi speed. Without an ALTR, the baseline aircraft has a taxi speed (no braking) of about 51 knots at typical air superiority mission landing weight and idle power. With an ALTR, this taxi speed could be reduced to virtually 0 knots if desired.

For the current carbon brakes used on the F-15C model, it has been estimated that a brake set will last for 1000 landings, including typical taxi profiles. This estimate was based on results of laboratory service life wear - dynamic spectrum tests. Sufficient field wear data is not yet available on this current brake material, however, to correlate the estimated brake life characteristics against actual field life. It has also been estimated that 46% of the brake wear is incurred during the taxi operations. If an ALTR was used during taxi to eliminate all this brake wear, a set of brakes is estimated to last up to 1860 landings.

Based on the LCC groundrules and engine usage results (for average mission duration), the cost of approximately 1100 brake sets would be saved with ALTR utilization. Additional savings for ALTR utilization may be realized due to reduced maintenance time for worn brake replacement, as well as other brake-related maintenance for broken springs, etc., that might be reduced due to less severe brake usage during taxi.

Advanced Aircraft

Baseline LCC. The life cycle cost of the baseline ATS configuration was estimated using the McAir ACCM and same groundrules as for the baseline F-15C.

As with the F-15C, to compute fuel costs over the aircraft life cycle, the engine usage results were used to estimate the total engine run time per aircraft flight hour, and the average fuel consumption per engine run hour. From the usage results, 300 aircraft flight hours per year would yield an additional 159 ground hours for a total of 459 engine run hours per year. The average fuel consumption per engine run hour was estimated as 1551 gallons/hour for in-flight operation and 363 gallons/hour for ground operation.

The results of the baseline ATS life cycle cost analysis are broken down by the major components in Figure 22. The contribution of each element is again normalized with respect to the total LCC. For this configuration, research and development costs for both the airframe and engine are included.

3 Door ALTR LCC. The impact of the 3-door ALTR on the ATS aircraft life cycle cost has also been assessed. Based on the preliminary ALTR design layout, the engine-related LCC changes were altered as follows:

- o % Change in Engine Production Cost = +8.8
- o % Change in Engine Maintenance Cost = +1.0

- % Change in Engine CIP Cost = +8.8

BASELINE ATS LCC SUMMARY

LCC ELEMENT	CONTRIBUTION
* RDT&E	0.085
-AIRFRAME DESIGN/DEV	0.008
-ENGINE DEV TO MQT	0.015
-FLIGHT TEST ENGINE COST	0.003
-AVIONICS DEVELOPMENT	0.008
-OTHER	0.051
* INVESTMENT	0.421
-AIRFRAME	0.159
-ENGINES	0.073
-AVIONICS	0.074
-SUBSYSTEMS	0.030
-OTHER	0.085
* O&S	0.494
-FUEL	0.252
-ENGINE MAINTENANCE	0.029
-ENGINE CIP	0.012
-OTHER	0.201
TOTAL:	1.000

Figure 22

The engine usage results for this configuration were again used to estimate the average fuel consumption per engine run hour, which were 1494 gallons/hour in-flight operation and 363 gallons/hour for ground operation. The ground time/flight ratio for this configuration was virtually the same as the baseline vehicle.

The LCC results for this configuration are compared to the baseline ATS in Figure 23. The total LCC of the ALTR-equipped configuration is 1% lower than the baseline ATS aircraft. The lower airframe and fuel costs resulting from the 10% lighter aircraft with 13% less internal fuel capacity were nearly completely offset by the increases in propulsion system development and production costs. However, the resulting 1% reduction still provides a substantial absolute savings.

3-DOOR ALTR IMPACT ON ATS LCC

LCC ELEMENT	BASELINE ATS	ATS WITH 3-DOOR ALTR	ΔLCC $M
* RDT&E	0.085	0.083	-59
-AIRFRAME	0.008	0.008	-20
-ENGINE/NOZZLE	0.015	0.016	+21
-FLIGHT TEST ENGINE	0.003	0.003	+8
-AVIONICS	0.008	0.008	+0
-OTHER	0.051	0.049	-59
* INVESTMENT	0.421	0.420	-44
-AIRFRAME	0.159	0.155	-128
-ENGINES	0.073	0.079	-214
-AVIONICS	0.074	0.074	0
-SUBSYSTEMS	0.030	0.029	-43
-OTHER	0.085	0.083	-59
* O&S	0.494	0.487	-266
-FUEL	0.252	0.243	-300
-ENGINE MAINTENANCE	0.029	0.029	-2
-ENGINE CIP	0.012	0.013	+35
-OTHER	0.201	0.202	-29.5
TOTAL	1.000	0.990	-369

Figure 23

Summary of LCC Effects

In summary, the T/S and R/V ALTRs caused increases in LCC of 2.4% and 3.8% respectively when installed on an aircraft whose size had been previously fixed without regard to short landing capability. However, when a short landing requirement was set at the aircraft design stage, ALTR reduced the LCC by approximately 1% for the ATS aircraft.

Conclusion on ALTR Equipped Aircraft LCC Efforts

When ALTRs are installed as a retrofit action to reduce landing ground roll, there is likely to be a cost penalty whose size will depend upon the particular installation chosen. From this study an installation downstream of the nozzle throat was shown to have a smaller impact on cost than the upstream installation. This additional cost must ultimately be weighed against the benefits of being able to land within a reduced distance. Only then can the full worth of ALTR be judged. However, when the ALTR is installed at the aircraft design stage, definite cost advantages may occur compared to other methods of achieving short landing, ground roll.

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