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PERFORMANCE FLIGHT TESTING OF AN F-111C AIRCRAFT

by
Mr. Geoff Brian, BE (Aero), DSTO - AOD, Melbourne, Australia.
Mr. Bruce Woodyatt, BE (Aero) , DSTO - AOD, Melbourne, Australia.
Mr. Kelvin Bramley, BE (Aero) , DSTO - AOD, Melbourne, Australia.
Mr. Andrew Snowden, BE (Aero) , DSTO - AOD, Melbourne, Australia.
SQNLDR Cameron Morris, BSc QTP, RAAF - ARDU, RAAF Base Edinburgh, Australia.
SQNLDR Todd Russell, BE (Aero) MSc FTE, RAAF - ARDU, RAAF Base Edinburgh, Australia.

Abstract

The Royal Australian Air Force (RAAF) expects to be the sole operator of F-111 aircraft after 1998. To maintain reliable operation of the ageing F-111C fleet, the aircraft's Pratt and Whitney (P&W) TF30-P-103 engines are being replaced with higher performance P&W TF30-P-109RA engines. This will result in a unique variant of the F-111 aircraft. A flight trial was conducted by the RAAF to characterise the change in performance of an F-111C aircraft installed with TF30-P-109RA engines. Traditional performance test techniques, dynamic manoeuvring and mathematical modelling were used to evaluate aircraft performance and airframe lift and drag characteristics. The take off and climb performance of the trial aircraft were found to closely match data for the F-111G variant. Descent performance of the trial aircraft did not match F-111G data, and this was attributed to the Mach Idle Bias controllers fitted to the TF30-P-109RA engines. Lift and drag characteristics were verified with manufacturers data, permitting cruise and combat performance to be estimated using mathematical models of the airframe aerodynamics and installed engine performance. The F-111C/TF30-P-109 aircraft has been approved for operational flying as a result of the trial.

Introduction

To ensure the reliable operation of the F-111C aircraft, and to reduce the burden of maintaining an ageing fleet, the RAAF are currently replacing the aircraft's Pratt and Whitney (P&W) TF30-P-103 engines with the higher performance TF30-P-109RA engines. This will result in a unique variant of the F-111 aircraft.

The new engines are expected to provide up to 10% more thrust than the current engines at both military and maximum afterburner operating conditions. Although the TF30-P-109RA engine has previously been installed in the EF-111A and F-111D, performance data relating to these aircraft are not applicable to the F-111C/TF30-P-109RA configuration due to the differences in wing span, airframe weight and engine intake design. However, the F-111G (FB-111A) aircraft, which has P&W TF30-P-107 engines, has the same overall dimensions as the F-111C, but a different engine intake design. Since the performance of TF30-P-107 closely matches that of the TF30-P-109RA, the modified F-111C was expected to have similar performance characteristics to the F-111G.

A flight trial was conducted by the RAAF Aircraft Research and Development Unit (ARDU), with assistance from P&W and the Defence Science and Technology Organisation (DSTO), to characterise the change in performance of an F-111C aircraft fitted with TF30-P-109RA engines, Figure 1. The flight trial aimed to demonstrate that the performance data for the F-111G were representative of the F-111C/TF30-P-109RA. It also sought to confirm the safe operation of the TF30-P-109RA engines throughout the current F-111C flight envelope.

Figure 1 : F-111C Trial Aircraft (A8-132)

Traditional performance flight test techniques were used to evaluate the take off, climb and descent performance of the aircraft, while dynamic manoeuvres were used to evaluate aircraft cruise and combat performance. The use of trimmed cruise and level acceleration manoeuvres for the estimation of cruise and combat performance would have required approximately 50 flight hours. However, with the use of dynamic manoeuvres, the trial was completed in approximately 20 flight hours.

Mathematical modelling techniques were used to assist in the development of the flight test schedule. The aerodynamic characteristics of the F-111C(1), together with a P&W model of the TF30-P-109RA engine(2), were used to predict the performance of the modified aircraft prior to the flight trial. The aircraft's climb ceiling, cruise performance, and drift down characteristics were modelled, as well as the flight path and attitude angles expected during the dynamic manoeuvres.

This paper describes the flight trial, with particular emphasis on the techniques used to estimate the performance characteristics of the aircraft. The pre-trial modelling activities and the techniques used to reduce the recorded data are discussed. The results from the trial showing the improved performance of the F-111C are also reported. Finally, flight trial

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results are compared with F-111G performance data.

Aircraft weight, altitude, rate of climb and descent, airspeed and range have been expressed using Imperial units in this paper to conform with flight trial and manufactures data. Normal load factor is indicated in multiples of gravitational acceleration (g), using the conventional definition in which the normal load factor in straight and level flight is 1g and in free fall is 0g.

Flight Trial

The flight trial program was divided into two phases, the first focusing on safety of flight, and the second on aircraft performance.

Phase one was conducted to certify the operational safety of the F-111C aircraft fitted with TF30-P-109RA engines, and to ensure the aircraft's sub-systems continued to function normally. A Safety of Flight test was performed during December 1996, in which the aircraft was flown to the limits of the current F-111C envelope. Throughout this envelope, the aircraft's engines and sub-systems were shown to perform satisfactorily.

Phase two was conducted to characterise the change in performance of the aircraft resulting from installation of the higher thrust engines. Flying was performed by ARDU at the Edinburgh Air Force Base during February and March of 1997. A total of nine flights were conducted consisting of an operational safety/instrumentation shakedown flight; six flights gathering data to characterise clean aircraft performance; one flight gathering data for the aircraft fitted with stores; and a ferry flight returning the aircraft to Amberley Air Force Base. Each of these flights included traditional performance test manoeuvres to gather take off, climb and descent data, as well as dynamic manoeuvres for the estimation of the aircraft's cruise and combat performance.

The take off for each flight was performed starting from a stationary condition with both engines set at maximum afterburner. Data for these events were used to calculate ground run distance and lift off airspeed.

The aircraft's climb performance was evaluated at both military and maximum afterburner thrust. Data were recorded between pressure altitudes of 2 000 ft and 30 000 ft, or up to the 300 fpm rate of climb military thrust ceiling. The climb speed schedules for the F-111G[4] were used during the flight trial, allowing the measured data to be compared with published performance data. The time required to climb to altitude, and the fuel burnt were calculated from the trial data.

Idle thrust and auto Terrain Following (TF) descents were conducted using F-111G[4] speed schedules. Data were gathered for pressure altitudes of 30 000 ft down to 2 000 ft.

"Drift down" refers to the procedure followed in the event of an engine failure during normal cruising flight. During a drift down, the pilot transitions the aircraft from the normal two-engine cruising altitude to the lower, single-engine, cruising altitude. Drift down data were gathered during the flight trial, where one engine was set at military thrust, and the other engine windmilling. The data were used to calculate the time to descend, the fuel burnt, and the drift down range.

The cruise and combat performance of the aircraft, together with the lift and drag characteristics, were evaluated using data gathered from the dynamic manoeuvres. These consisted of roller-coaster manoeuvres performed for a range of wing sweep angles, altitudes and airspeeds. Execution of a roller-coaster manoeuvre involved trimming the aircraft in steady level flight; performing a push-over to reduce the normal load factor to approximately 0g, then pulling up to increase the normal load factor to 4g or until buffet was induced. Recovery from the manoeuvre was achieved by either a push-over manoeuvre or rolling the aircraft through 135° and recovering to steady level trimmed flight with positive normal load factor. A typical normal load factor time history for a roller-coaster manoeuvre is shown in Figure 2. A rate of change in normal load factor of approximately 0.5g per second was used throughout the roller-coaster manoeuvre. This allowed data to be gathered for a large range of angles of attack while minimising the variation in the airspeed and altitude.

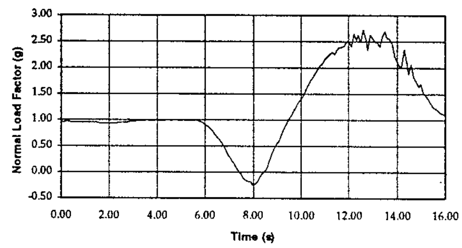


Figure 2 : Roller-coaster Manoeuvre

At each test point, three roller-coaster manoeuvres were performed, and the effects of variation in manoeuvre technique and atmospheric conditions were averaged.

A series of straight and level trim manoeuvres were flown to gather data for the verification of the TF30-P-109RA engine performance model. These manoeuvres were flown with one engine windmilling, and the other adjusted to maintain trimmed straight and level flight. Trim manoeuvres were also flown with both engines operating normally.

Pre-Trial Modelling

Prior to the commencement of the flight trial, DSTO predicted some of the performance characteristics of the trial aircraft, using mathematical modelling techniques. Aircraft performance and flight dynamic databases had previously been compiled for an F-111C fitted with P&W TF30-P-103 engines. These databases brought together aerodynamic parameters, as well as engine thrust and fuel flow information, and were compiled using wind tunnel and flight test data from a number of sources, including the aircraft manufacturer. In the past, the databases have been used extensively to estimate the flight dynamic and performance characteristics of the F-111C aircraft, and have produced results which correlate very well with published data, particularly the F-111C Performance Manual[3].

The existing databases were modified to represent the expected performance of the trial aircraft. The installation of the TF30-P-109RA engine into the F-111C airframe was not expected to significantly affect the aerodynamic characteristics of the aircraft. A TF30-P-9 engine performance model[2], obtained from P&W, was used to estimate the installed thrust and fuel flow characteristics of the trial engines. It should be noted that the TF30-P-109RA is a modified TF30-P-9 engine that complies with Time Compliance Technical Order, TCTO 2J-TF30-834[6]. The engine model* was used to estimate in-flight thrust and fuel flow data for International Standard Atmosphere (ISA) and non-ISA conditions.

Aircraft performance characteristics including best range cruise altitude and Mach number, climb, 300 fpm military thrust ceiling, and drift down were estimated for operations in ISA and ISA+15° conditions, at a range of aircraft weights, and store configurations. In addition, the single engine best range cruise performance of the aircraft was estimated, where one engine was set at military thrust, and the other engine was windmilling or in a locked rotor state.

The behaviour of the aircraft throughout the planned roller-coaster manoeuvres was simulated using a comprehensive flight dynamic model of the F-111C. The simulations showed that for manoeuvres performed at higher altitudes and slower airspeeds, the pull-up to a normal load factor of 4 g could not be achieved. This was a result of the aircraft approaching the stall condition.

Prior to the flight trial, these data provided the flight crew with an indication of the expected performance of the aircraft. Post-flight, the results were used as a source of comparative data.

*Hereafter, the TF30-P-9 engine performance model will be referred to as either *engine model* or the *TF30-P-109RA engine model*.

Instrumentation

As part of a recent Avionics Update Programme (AUP), the trial aircraft was instrumented with a Flight Data Acquisition and Recording System (FDARS). This was used to record data from the aircraft's data buses, and instrumentation installed specifically for the trial. FDARS captured data from the Mission Computer, Display Multiplex (MUX) database, Avionics MUX, Armanent MUX and the Terrain Following Radar. In addition, data from a motion platform, containing accelerometers and angular rate gyros, and engine throttle position synchros were recorded. The motion platform was fitted for the trial to gather data independently of the integrated aircraft systems.

Engine Model Investigation

The TF30-P-109RA engine model was used extensively throughout the flight trial, particularly during the post-flight data analysis, and played an integral part in the success of the program. The engine model was used to estimate engine thrust for specific flight trial events, and together with aerodynamic data, provide pre-flight estimates of aircraft's performance characteristics.

The engine model represents a theoretical engine operating at the design specification, and produces data such as low-pressure and high-pressure compressor speeds (N1 and N2), engine pressure ratio (EPR), fuel flow and thrust at particular atmospheric and engine operating conditions. It can calculate the characteristics of either an uninstalled, or installed engine.

In contrast, the flight trial engines were mid-life engines and not overhauled to the design specification. Therefore, the performance of the trial engines was expected to be degraded compared to that of the theoretical model. Consequently, an investigation was conducted to ascertain the validity of using the engine model to estimate the performance of the trial engines.

Uninstalled Engine

Prior to the flight trial, the TF30-P-109RA engines were put though acceptance tests at the Amberley Air Force Base engine test facility. A variety of parameters were recorded, including N1, N2, EPR, thrust and fuel flow, at discrete throttle settings between Idle and Maximum Afterburner. These data were compared with engine model data, calculated using the same atmospheric conditions experienced during the tests.

The engine model was used to calculate data at Idle, Military, and discrete afterburner throttle settings. Data was also produced for arbitrary throttle settings between Idle and Military. To make direct comparisons with the test cell data, it was necessary to interpolate the engine model data. It was shown that when the engine model data were interpolated to the observed fuel flow, the differences between test cell and calculated data were minimised. The results for EPR and N2 were shown to be within 2%, while those for N1 and thrust were within 4%. Figure 3 shows a comparison of test cell and engine model EPR as a function of corrected fuel flow.

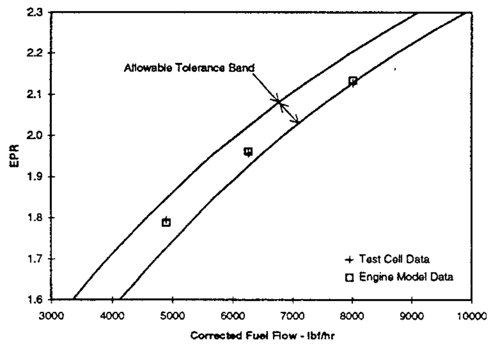


Figure 3 : Uninstalled Left Engine EPR

It was concluded from the analysis, that the engine model was representative of the uninstalled engine characteristics.

Installed Engine

In the absence of appropriate engine instrumentation, the engine model was used to estimate the installed thrust of the TF30-P-109RA. During the flight trial, a series of straight and level trim manoeuvres were flown to provide verification data.

The engine model was able to model the ram efficiency effects of the Triple Plow I intake, as fitted to F-111C aircraft. The air bleeds and power extraction required to operate the aircraft's avionics and environmental systems, were also included. Data representing the air bleeds and power extraction of an F-111C fitted with TF30-P-103 engines[7] were used, as data for the F-111C/TF30-P-109RA were unavailable. The F-111C/TF30-P-103 data were assumed to be representative since the trial aircraft's avionics and environmental systems remained unchanged.

The engine model did not account for changes in the intake momentum drag, spillage drag, or apparent nozzle drag. Again, data for an F-111C fitted with TF30-P-103 engines[7] were assumed to representative of the trial aircraft. The thrust data from engine model were corrected for these drag effects.

Engine data recorded during the trim manoeuvres, including N1, N2, and EPR, were compared with estimates from the engine model. In most cases, the engine model estimates were found to exceed the trial data.

The results for EPR and N1 were shown to be within 4% of the trial data, while those for N2 were within 2%. Figure 4 illustrates the difference between the engine model EPR and the trial data for the same corrected fuel flow.

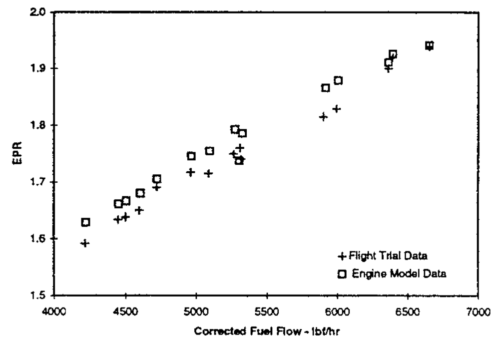


Figure 4 : Installed Left Engine EPR

The assumptions made when modelling engine the installation effects may explain, in-part, why data from the engine model exceeds the trial data. The trial aircraft's air bleed and power extraction requirements may have increased from those published, due to modernisation of the aircraft's systems. In addition, differences in the intake mass flow requirements between the TF30-P-109RA and TF30-P-103 engines may affect the intake momentum and spillage drag components. Also, variation between the trial aircraft's intake and the ideal representation included in the engine model, may contribute to the observed differences.

Despite these differences between the engine model and trial data, the model was considered to be representative of the installed performance of the flight trial engines.

Data Reduction and Analysis

Take Off/Climb/Descent

Take off distances were calculated using radar altimeter data to locate the precise lift-off point, and GPS data to determine the ground run. The take off speed was defined as the indicated airspeed corresponding to the lift-off point.

Corrections were applied to the climb and descent data to reference the observed rate of climb/descent to ISA conditions[5]. Time to altitude, the fuel burnt, and the distance travelled were calculated for all climbs and descents.

Drift Down

In the event of an engine failure, a drift down procedure is followed. The operational procedure for RAAF F-111[8][9] is to:

1. Maintain the initial altitude until the drift down airspeed is achieved.

2. In the drift down, maintain the drift down airspeed until a 300 fpm rate of descent is achieved

3. Allow the airspeed to bleed off to the best range single engine cruise Mach number, while slowly descending to the single engine best range altitude.

During the drift down, and in the subsequent single engine cruise, military thrust is selected on the operating engine, while the inoperative engine is either in a windmilling or locked rotor condition.

For the drift down manoeuvres conducted during the trial, the inoperative engine was windmilling and the operative engine set to military thrust. Fuel flow data for the operative engine were used to calculate the fuel burnt, while the distance travelled was calculated from GPS data.

Lift and Drag Characteristics

Data recorded during roller-coaster manoeuvres were used to calculate the lift and drag characteristics of the aircraft for a range of angles of attack, at near constant Mach number and altitude. This was accomplished using measured linear accelerations and angular rates from both the aircraft's Standard Inertial Navigation Unit (SINU), and the motion platform. Inertial velocities and aircraft attitude angles were also measured from the SINU, which, with corrections for the local wind, permitted the true airspeed of the aircraft to be calculated.

Accelerations and velocities measured from the SINU were corrected for the instrumentation position offset from the centre of gravity of the aircraft, and transformed to aircraft body-axes using Euler transformation techniques[10].

Independently, the motion platform angular rates and accelerations were corrected for instrumentation position offset from the aircraft centre of gravity, and integrated to yield aircraft attitude angles, angle of attack, angle of side slip, body-axes component velocities and the true airspeed of the aircraft. These angles and velocities were compared with values derived from the SINU, and showed excellent agreement, see Figure 5.

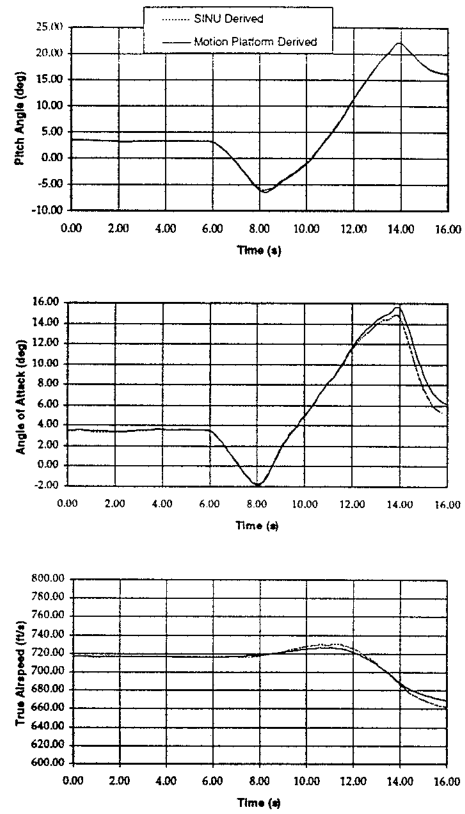


Figure 5 : SINU & Motion Platform Data Comparison

A high level of confidence in the data and reduction techniques was gained from these results.

The SINU body-axes accelerations were transformed to flight-path axes, and the accelerations normal to, and along the flight path were determined. The flight path normal (A_n) and axial (A_a) accelerations, together with the aircraft gross weight (W) and estimated installed thrust (F_g), were used to calculate aircraft lift (C_L) and drag (C_D) coefficients throughout the roller-coaster manoeuvre.

$$C_L = \frac{1}{\bar{q}S}\left[\left(\frac{W}{g}A_n\right) + W\cos(\gamma) - F_g\sin(\alpha + i_T)\right] \quad (1)$$

$$C_D = \frac{1}{\bar{q}S}\left[F_g\cos(\alpha + i_T) - \left(\frac{W}{g}A_a\right) - W\sin(\gamma)\right] \quad (2)$$

In these equations, $\bar{q}$ represents the dynamic pressure, S the wing reference area, α the manoeuvre angle of attack, γ the flight path angle, and i_T the thrust line inclination angle.

The lift and drag coefficients, which were plotted against the manoeuvre angle of attack, and the lift-drag polars, were compared with manufacturer's data[1], as shown in Figure 6.

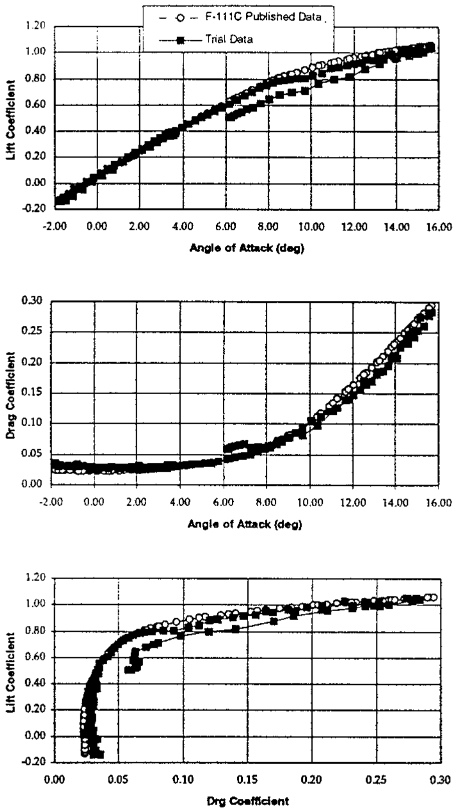


Figure 6 : Airframe Lift - Drag Characteristics

Cruise Performance

Specific range (S_R) is a measure of the cruise performance of an aircraft, and is defined as the ratio of the distance travelled to the amount of fuel burnt in covering that distance. It may be calculated using the relationship:

$$S_R = \frac{V}{\dot{W}_f} \qquad (3)$$

where V is the true airspeed of the aircraft, and $\dot{W}_f$ the engine fuel flow.

To estimate the cruise performance, the fuel flow corresponding to trimmed level flight, at a selected airspeed, was calculated using the results from the lift-drag investigation together with TF30-P-109RA engine model data. The fuel flow and airspeed were then used to calculate specific range. This technique allowed cruise performance to be evaluated throughout the flight envelope, and at atmospheric conditions different from those experienced during the trial.

Combat Manoeuvring

The thrust limited manoeuvre load factor and the maximum sustained rate of turn are measures of an aircraft's combat capability. The thrust limited manoeuvre load factor is defined as the maximum load factor that can be achieved during a turn at a constant airspeed and altitude. It coincides with the flight condition where the available thrust from the engines equals the thrust required to overcome the airframe drag. Information from the lift-drag investigation, together with TF30-P-109RA engine model estimates of the available thrust at military and maximum afterburner, were used to calculate the thrust limited manoeuvre load factor. The rate of turn was then calculated at the same airspeed. This technique allowed combat performance data to be estimated at the same flight conditions as published in the F-111C and F-111G performance manuals(3)(4).

Results and Discussion

Performance Prediction

The 300 fpm military thrust ceiling capability for the aircraft, in the clean configuration, was estimated from excess power calculations at several weights and flight conditions, as observed during the flight trial. Table 1 shows these results, together with data from the F-111C, and the F-111G performance manuals.

Table 1 : Military Thrust Ceiling

Aircraft Weight (lbf)	Flight Trial (P-109)	F-111C (P-103)	F111G (P-107)	Estimated (P-109)
	Altitude (ft)			
75 482	34 350	33 000	34 400	33 808
78 332	32 500	32 000	33 380	32 845

The results show that there is an increase in the military thrust ceiling capability for an F-111C when fitted with TF30-P-109RA engines. In addition, the performance of the flight trial aircraft was close to that of an F-111G. However, it should be noted that the F-111C/TF30-P-103 and the F-111G performance data represent operations at ISA conditions.

The predicted data were within 1.5% of the flight trial results, and do not show any particular bias. Any differences between the predicted and observed data may be due to the interpolation of the predicted results to represent the non-standard atmospheric condition, and/or the accuracy of the measured flight trial data.

Take Off/Climb/Descent

The flight trial results showed that the take off distances were within 200 ft of data published in the F-111G performance manual. In addition, the take off speeds were within 2 knots of the published indicated airspeeds. Similarly, the climb performance of the aircraft was found to compare well with F-111G data. The differences in the comparative results were within the accuracy of the aircraft's instrumentation and systemic measurement tolerances.

The descents at idle thrust were found to compare poorly with F-111G data. These differences were attributed to the Mach Idle Bias (MIB) controller fitted to the TF30-P-109RA engine. At idle thrust, the MIB controller maintains a higher N2 spool speed than the TF30-P-107 engine in the F-111G, resulting in higher thrust and fuel flow. Therefore, an increase in the time, fuel burnt and distance travelled during the descent would be expected.

Drift Down

The flight trial drift down data were compared with F-111G aircrew notes[11]. These results showed that the flight trial distances, and times were up to 15% greater than the published values. However, values for the fuel burnt were only 3% greater. It should be noted, that the flight trial aircraft commenced each drift down at a weight of approximately 77 000 lbf, whereas the F-111G pilot notes use a reference weight of 68 000 lbf. However, the differences in the results have been attributed primarily to the higher thrust and fuel flow of the TF30-P-109RA engines, at military thrust.

Lift and Drag Data Verification

The estimated lift and drag characteristics of the trial aircraft were compared with manufacturers data[1]. The results showed that the differences in the lift and drag coefficients were less than 5% for trimmed flight.

It is evident in the graph of lift coefficient versus angle of attack, Figure 6, that a hysteresis occurs in the trial data as the aircraft is manoeuvred around the trim condition. The hysteresis may be attributed to the dynamic nature of the roller-coaster manoeuvre not truly representing the steady-state characteristics of the aircraft, and appears to be proportional to the magnitude of the aircraft pitch rate. The value calculated using equation (1) represents the total aircraft lift coefficient, including any variation due to pitch rate. The total lift coefficient may be adjusted to represent the steady state characteristics, but this requires prior knowledge of the dynamic components of the aircraft aerodynamics. Alternatively, a slower rate of change in normal load factor could have been used throughout the roller-coaster manoeuvres. However, this may have resulted in significant variations in airspeed and altitude. The drag coefficients calculated from the trial data were not significantly affected by the dynamic nature of the roller-coaster manoeuvres, and compare well with manufacturers data.

Although there were differences between the trial and manufacturers aerodynamic data, the comparative results were generally good. It was concluded, that the manufacturers data were representative of the aircraft's aerodynamic characteristics in trimmed, and slow manoeuvring flight. The verification of the manufacturers data permitted cruise and combat performance to be estimated using a mathematical model incorporating the manufacturers aerodynamic data, and TF30-P-109RA engine performance model.

Cruise Performance

Specific range data for the current F-111C and F-111G aircraft were compared with data estimated for the F-111C fitted with TF30-P-109RA engines. The results show an increase in specific range in-excess of 2% compared with the current F-111C[3] and 5% compared with the F-111G[4] aircraft.

Combat Manoeuvring

The F-111C aircraft fitted with TF30-P-109RA engines showed an increase in rate of turn capability compared with the current F-111C[3], particularly at high subsonic airspeeds. Published data for the rate of turn capability of the F-111G aircraft was unavailable. However, the thrust limited manoeuvre load factor characteristics compared well.

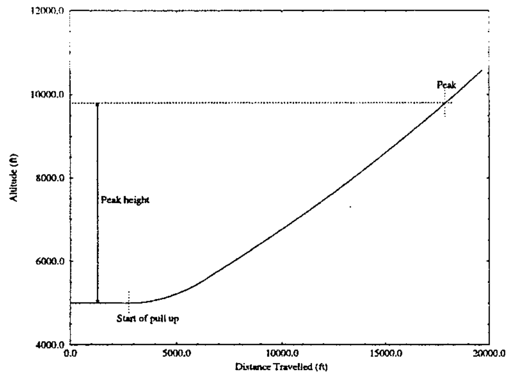
Peak Height Capability

F-111 aircraft are fitted with a Terrain Following Radar (TFR) providing a low altitude terrain following (TF) and obstacle avoidance capability. The TFR can compute avoidance trajectories to ensure that safe separation is maintained between the aircraft and oncoming obstacles at distances from 1 000 ft to 36 000 ft. A climb manoeuvre, known as the auto TF climb, will be initiated by the TFR to avoid oncoming obstacles.

During an auto TF climb, the aircraft's airspeed is permitted to bleed-off until a minimum allowable value is achieved. The minimum allowable airspeed is a function of wing sweep angle and weight, and is intended to prevent the aircraft from exceeding angle of attack limits in the event of the TFR initiating an emergency fly-up manoeuvre. On reaching this airspeed, the aircraft will have travelled a distance equal to the range for which the TFR was computing obstacle avoidance.

The maximum change in altitude that can be achieved while avoiding an obstacle, and not exceeding aircraft limitations[8][9], is known as the peak height capability.

In the absence of flight trial data, mathematical modelling techniques were used to estimate the peak height capability of the aircraft by simulating auto TF climb manoeuvres. A flight dynamic model of the F-111C aircraft, together with the TF30-P-109RA engine performance model were used for this purpose. The simulated climb trajectories were designed such that the aircraft would not exceed operational limits, and the airspeed overhead the obstacle corresponded to the minimum allowable airspeed. A typical auto TF climb trajectory, calculated using the flight dynamic model, is shown in Figure 7, together with the change in airspeed.



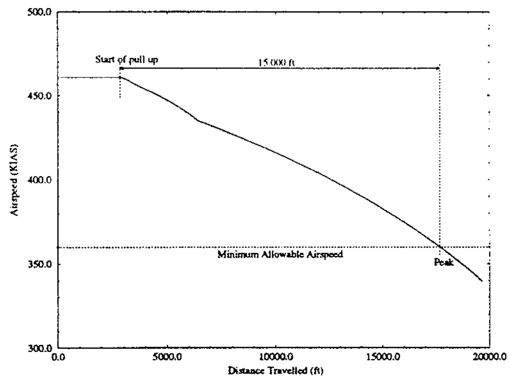


Figure 7 Altitude and Airspeed Profiles calculated for Auto TF Climb.

Table 2 and 3 compare the peak height capability of the current F-111C[3] and F-111G[4] aircraft, with data calculated using the flight dynamic model. These data represent the peak height capability for a clean aircraft weighing 60 000 lbf, at three wing sweep angles, climbing at military thrust. Data are shown for three velocity increments (ΔV), where ΔV is defined as the difference between the initial airspeed and the minimum allowable airspeed. The results show that the F-111C fitted with TF30-P-109RA engines has an increased peak height capability compared with both the current F-111C[3] and F-111G[4] aircraft.

The increase in TF peak height capability is consistent with the increase in military thrust available from the TF30-P-109RA engines.

Table 2 : Peak Height Comparison with Current F-111C aircraft

	Wing Sweep					
	44°		54°		72°	
ΔV	Peak Height (ft)					
(KIAS)	Model	F111C	Model	F111C	Model	F111C
50	3700	2400	3000	2000	3300	1600
100	5100	4400	5200	4000	4900	3400
150	7000	6400	6800	6000	6200	5600

Table 3 : Peak Height Comparison with F-111G aircraft

	Wing Sweep					
	44°		54°		72°	
ΔV	Peak Height (ft)					
(KIAS)	Model	F111G	Model	F111G	Model	F111G
50	3700	2800	3000	2600	3300	2200
100	5100	4800	5200	4400	N/A	N/A
150	7000	6500	6800	6000	N/A	N/A

Conclusion

The F-111C fleet, operated by the Royal Australian Air Force, are to have their Pratt and Whitney TF30-P-103 engines replaced with higher performance Pratt and Whitney TF30-P-109RA engines. This will ensure reliable operation of the aircraft through to the proposed withdrawal date from service. The Aircraft Research and Development Unit, of the Royal Australian Air Force, conducted a flight trial to certify operational safety of the modified aircraft, and to characterise the change in performance.

Traditional performance flight test techniques, together with dynamic manoeuvre techniques, were used to evaluate the aircraft's performance. Data from the dynamic manoeuvres were used to estimate the lift and drag characteristics of the aircraft, as well as the cruise and combat performance. Traditional techniques for evaluating these characteristics would have required approximately 50 flight hours, whereas the dynamic manoeuvres permitted the trial to be completed in 20 flight hours.

Mathematical modelling techniques were extensively used to predict aircraft performance data prior to the flight trial, and during post-flight data analysis. Integral to the success of the modelling activities was knowledge of the installed engine thrust. This was estimated using a Pratt and Whitney TF30-P-109RA engine performance model. The engine model was shown to be representative of both the uninstalled and installed performance of the flight trial engines.

Results from the trial were compared with performance data published for the F-111G aircraft, as well as manufacturer's aerodynamic data. The take off and climb performance of the trial aircraft were found to closely match data for the F-111G. However, the descents at idle thrust were found to compare poorly. Lift and drag characteristics were verified with manufacturer's data, permitting cruise and combat performance to be estimated. The F-111C/TF30-P-109RA aircraft was shown to have an improved cruise performance and combat manoeuvring capability.

As a result of the success of the file trial, the F-111C/TF30-P-109 aircraft has been approved for operational flying.

References

(1) General Dynamics, Fort Worth Division, Performance Data Substantiation for Regular Flight Manual F-111C Aircraft Appendix A - Clean Airplane Trimmed Drag Polars, FZA-12-5003 APP A, USA, 10 April 1969.

(2) Pratt & Whitney Aircraft, Specification No. A-6123-A, Model TF30-P-9 Engine, Connecticut, USA, July 1970.

(3) Royal Australian Air Force, Flight Manual Performance Data F-111C, AAP 7214.003-1-2, Issued February 1973, Amended July 1987.

(4) Royal Australian Air Force, Performance Manual F111G, AAP 7214.014-1-1, Issued March 1994.

(5) Royal Australian Air Force - Aircraft Research and Development Unit, Formal Report - TASK 0231 : F/RF-111C TF30-P-109 Engine Upgrade Project, February 98.

(6) Banta, A J and Hiller, C M, EF-111A/TF30-P-109 Limited Performance and Propulsion Flight Test, Sacramento Air Logistics Center, USA, November 1987.

(7) General Dynamics - Fort Worth Division, Propulsion Data Substantiation Regular Flight Manual F-111C, FZA-12-5002, USA, 1 February 1969.

(8) Royal Australian Air Force, Flight Manual F111C, AAP 7214.003-1, Issued August 1974, Amended January 1989.

(9) Royal Australian Air Force, Flight Manual F111G, AAP 7214.014-1, Issued March 1994, Amended March 1995.

(10) Etkin B., Dynamics of Atmospheric Flight, John Wiley & Sons, New York, United States of America, 1972.

(11) F-111G Aircrew Check List.