IDEA-1144-69
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31 December 1969

MEMORANDUM FOR THE RECORD

SUBJECT: U-2R Flight Performance Data Analysis

REFS : A - LAC Report No. SP-1125, 28 Nov 1966 "Manufacturer's Model Specification High Altitude Reconnaissance Airplane"

B - LAC Report No SP-1233, 1 Sept 1967 "Performance, Stability and Control of the L-351 Airplane"

C - LAC Report No SP-2081, 16 Sept 1968, "Maximum Power Design Weight Mission Aircraft S/N 055"

D. LAC Report No SP-2096, 8 Oct 1969 "Aircraft Performance Tests" (U-2R)

E. Pratt & Whitney Aircraft Specification No N-2614-G, 10 Feb 1958 with Appendix B, 8 Nov 1965, Reissued: 25 May 1967. Model J75-P-13B Engine

INTRODUCTION

An analysis has been made of all significant flight data available to date from U-2R aircraft in order to evaluate the performance of the flight test aircraft relative to the performance predicted in the Model Specification (Reference A) and in the more complete performance report LAC Report No SP-1233 "Performance, Stability and Control of the L-351 Airplane" (Reference B). A secondary purpose of this analysis was an evaluation of the performance of the actual operational aircraft relative to the model specification and the flight test aircraft. An analysis of engine performance relative to the engine specification and its effect on airplane performance was also included.

The data analysed herein includes recorded flight data from the instrumented flight test aircraft (051), recorded data from an operationally configured aircraft (055) and pilot recorded fuel curve data from operational aircraft Serial Numbers 052 through 058 inclusive. Data has been analysed from a total of approximately 25 maximum altitude flights and the results are displayed in the attached curve sheets.

The airplane performance parameters evaluated are altitude capability and range factor as a function of gross weight and the engine performance parameters are Engine Pressure Ratio (EPR) and fuel flow versus altitude. Since aircraft performance is affected by engine performance and engine performance (EPR) is proportional to corrected exhaust gas temperature, which is a function of exhaust gas temperature and free air temperature, both of these significant temperatures are plotted for all flights. Engine EPR is the best indicator of engine output (thrust) available from cockpit instruments and while it is more directly a measure of the ability of the gas generator portion of the engine to develop a high pressure gas (the stuff from which thrust is made) it does not include the effects of nozzle/ejector efficiency which also affects final thrust output. For a given aircraft design i.e., a given aircraft engine installation, EPR is a direct measure of thrust capability. The range factor term used here is gross weight x velocity ÷ fuel flow

CONCLUSIONS

A number of significant conclusions relative to the performance of the U-2R aircraft and the J75-P-13B engine can be reached as a result of this data analysis.

A. The performance of flight test aircraft (051) duplicates that presented in LAC SP-1233 on both altitude and range factor for a given gross weight. The actual altitude of the aircraft for a given gross weight was somewhat below the aircraft specification due to the fact that the engine thrust was somewhat below the engine specification performance. When the aircraft performance is corrected to that which would result from specification engine performance, the aircraft altitude capability for a given gross weight agrees with the values given in the Specification Performance Report. (See Figures 1 and 5).

The Range Factor data for the flight test aircraft also agrees well with predicted performance when engine fuel flow is corrected to the values predicted in the engine specification. (See Figure 5A).

B. Average performance of the operationally configured aircraft is quite predictable and falls generally about 1200 to 1300 feet below the predicted aircraft specification performance on an altitude versus gross weight basis. This is 200 to 300 feet below the lower limit of the band of performance shown in the U-2R-1 Manual. This 1200-1300 ft. altitude decrement occurs as a result of an average engine thrust deficiency of 3.5% below specification and an average operational aircraft drag increment of 5% above the predicted aircraft performance and the performance of the flight test aircraft. It is worth noting that this 5% drag penalty of approximately 55 pounds @ M_n .72 and 70,000 feet is equivalent to the dynamic pressure (or the drag with a C_D of 1.0) on an area of $1\frac{1}{2}$ square feet at this flight condition. It is indicative of the penalties which occur from adding proturberances of any kind externally on the aircraft. (See Figures 2, 2A and 3.) As shown in Figure 3A there is considerable scatter in values of fuel flow and range factor apparently due to the accuracy of pilot read cockpit data used to calculate these values. The average fuel flow and range factor show good agreement with engine and aircraft predicted values respectively. A special range calibration flight #23 was flown with aircraft #055 and these results are shown in Figures 6 and 6A and described in Reference C. As shown in Figure 6A, the range factor at all gross weights exceeds the specification value by an average of 2.1%. The total range at maximum altitude should exceed the specification value by about this amount.

C. A considerable amount of scatter exists in the cockpit read engine performance data. The EPR data in particular after correction to a standard day temperature results in values which range from 3.4% below to 1.7% above the specification value at 70,000 feet. This range of EPR values results in estimated thrust values which range from about 5.5% below specification to about 2.8% above specification. Engine fuel flow data while showing some degree of scatter generally agrees reasonably well with the engine specification value. This considerable variation in engine performance will be reviewed with airframe and engine contractor performance engineers to ascertain if any significant clues as to possible causes such as engine internal component performance or installation effects appear worthy of further study or investigation.

D. As would be expected, the effects of free air temperature on engine performance are quite significant. The very low free air temperatures, which exist at altitude in areas such as the Far East where altitude temperature profiles approximate or are colder than a defined standard tropical day, provide a substantial increase in high altitude engine thrust and improved aircraft altitude capability. (See Figures 4 and 4A).

E. A 1962 Standard day is a better standard than a 1959 standard day and should be used in all future high altitude aircraft programs. A 1962 standard day is a more typical day for flight test operations in the Edwards Air Force Base area and simplifies all calibrations and corrections. Writing specifications and predicting performance on a 1959 standard day basis results in somewhat optimistic performance for altitudes above 65,000 feet since actual temperatures above this altitude are generally warmer than a 1959 standard day.

DISCUSSION

This analysis is based on a review of all the significant flight data available from the U-2R aircraft and includes recorded data from the instrumented flight test aircraft and pilot recorded fuel curve data from operational aircraft. Aircraft and engine performance has been plotted and analysed from approximately 25 flights. In addition to aircraft and engine performance and the effect of engine performance on aircraft performance, the effects of ambient temperature and exhaust gas temperature levels on engine performance have been analysed. The correction factors for these various effects are as follows:

-1°C F.A.T. + .012 EPR

+1°C E.G.T. + .003 EPR

1% EPR 1.64% Thrust

1% Thrust 150 ft. of Altitude

NOTE: A 1°C lower free air temperature results in 4 times the improvement in EPR which results from a 1°C increase in EGT, due to the fact that EPR is proportional to corrected EGT (EGT/θ_2) where θ_2=Compressor inlet total temperature divided by standard day temperature at sea level.

While the pilot recorded fuel curve data exhibits a considerable amount of scatter compared to accurate recorded data from the flight test aircraft, significant trends in performance of the operational aircraft can be determined. Considerable scatter would be expected in the pilot recorded data due to the accuracy of cockpit instruments and the degree of accuracy utilized by various pilots in reading instruments and recording data as compared to flight recorded data on the flight test aircraft.

The engine specification EPR performance as shown on the curves is generally presented on the basis of either a 1959 standard day or a 1962 standard day and both are shown on most curves. On curves where performance is compared with specification, a 1959 day is generally used since the aircraft and engine specifications were based on this standard. However as stated earlier a 1962 standard day appears to be more representative of the free air temperature data presented in the report with the exception of the data obtained in the Far East. A 1959 standard day is based on a constant temperature of -56.5°C at U-2R cruise climb altitudes where a 1962 standard day is somewhat warmer than -56.5°C at altitudes above 65,600 ft. with the difference between the two standard days increasing with altitude. (See Figure 1)

25X1A The difference at [redacted] (a 1962 day being 2°C warmer than a 1959 standard day) results in a reduction in EPR of about 3/4 of 1%, 1.2% reduction in thrust and a reduction in altitude of 180 feet. In the Far East, temperature data more nearly approximates a tropical standard day altitude temperature profile which results in a significant boost in engine and aircraft performance at U-2R climb and cruise-climb altitudes and reduces the time required to reach a given penetration altitude.

The performance of the flight test aircraft (051) was reviewed primarily on the basis of a particular test flight (#81) where free air temperatures at altitude generally approximated a standard day. This data is shown in figures 5 and 5A and is summarized in Figure 1 where a comparison is also made of 051 performance with predicted values and the band of performance (altitude versus gross weight) presented in the U-2R-1 manual. The actual flight data for the test aircraft is approximately 500 ft. below the predicted altitude. However, when the thrust deficiency of the engine is accounted for, the altitude versus gross weight profile matches the predicted values. The actual performance of the engine (S/N 612621) installed in this test aircraft on flight #81 is also shown in Figure 1 where a comparison is made with engine specification EPR values. (Also see Fig 5 of Ref D.

Figure 2 represents an attempt to correct all engine EPR data at 70,000 ft. for variations in exhaust gas temperature and free air temperature. As can be seen from this figure there is a considerable amount of scatter in this corrected EPR data. The points shown on the aircraft (altitude versus gross weight) performance curve of figure 2 were obtained by taking the gross weight values from all the aircraft curves at 70,000 ft. and correcting the altitude to the altitude capability the aircraft would have with specification engine performance (i.e. an EPR of 3.26 on a 1962 standard day) at its actual gross weight at 70,000 ft. A 1959 standard day would raise all points about 180 ft. in altitude. This correction to the altitude versus gross weight data brings this aircraft data fairly well within the band of expected performance shown in the -1 manual. However, as stated previously an average operational aircraft with an average engine would fly 200 to 300 ft. below the manual band.

Figure 2A is probably one of the most significant curves of this report in so far as it portrays a good summation of operational aircraft performance. This plot is basically a lift-drag polar. The points shown are not actual data points but are based on gross weight and EPR values taken at 70,000
25X1A [redacted] from faired curves through the actual data

points. The effect of varying engine performance is accounted for by plotting gross weight versus EPR. This plot also tends to indicate that the cockpit read data is reasonably consistant and accurate and that the rather wide variation in EPR values among the various engines is real. Perhaps one should expect considerable variation in engine performance at these flight conditions since a multi stage axial flow engine is aerodynamically much more complicated than an aircraft at this high altitude low Reynolds number regime.

Figure 3 shows the uncorrected values of gross weight, EPR, EGT and FAT obtained from faired curves through the actual data plots at 70,000 feet. This is the data from which the corrected values of Figure 2 were obtained. Figure 3A presents fuel flow and range factor values at 70,000 ft. and while the data scatters over a fairly wide range, mean values are generally close to predicted. The wide degree of scatter which occurs in this data is apparently due to combined errors in the data (distance, time, and fuel remaining) from which fuel flow and range factor are calculated.

Figure 4 shows the very beneficial effect of cold (standard tropical day) free air temperatures at altitude on engine and aircraft performance. The tropical day effects on engine and aircraft performance on this curve are estimated. Aircraft 055 was used as a reference here since a more complete and well documented set of data was available from flight 23 of this aircraft and both the aircraft and engine demonstrated near average performance on this flight with near standard day free air temperatures. However, some of the actual data acquired in the Far East for verification of the final EPR schedule for engine operation and shown in Figure 4A provided excellent engine performance. This data was acquired on article 058 with engine serial number 612627 installed. Indications are that in addition to the beneficial cold temperature effect this engine also provides considerably better than average standard day performance. Additional fuel curve data obtained very recently (16 December 1969) on the same aircraft in the Far East with engine S/N 612626 installed also indicated excellent engine performance with EPR values as high as 3.35 at 70,000 feet.

The actual recorded data for flight 81 of aircraft 051 are shown in figures 5 and 5A. Figure 5A displays fuel flow and range factor data for the engine and airframe respectively.

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The FAT curve (figure 5) indicates that free air temperatures were somewhat colder than standard [redacted] and when this correction is applied to the engine fuel flow data an average curve would fall on the predicted curve. Since Range Factor equals gross weight x nautical miles per hour ÷ pounds of fuel per hour, correcting the slightly high values of fuel flow at altitudes [redacted] down to the engine specification curve would bring the aircraft range values up to their predicted values.

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Figures 6 and 6A are uncorrected flight recorded data from flight 23 of aircraft 055 and are particularly significant since they represent performance of an average aircraft and engine at near 1962 standard day conditions.

Figures 7 through 18 inclusive are the actual plots of uncorrected pilot recorded data from operational aircraft and generally result in rather well defined curves. The A series of curves, however, presenting engine fuel flow and aircraft range factor generally exhibit a rather wide degree of data scatter due apparently to an accumulation of errors in the cockpit instrument data from which they were calculated. Some of the best aircraft and engine performance data shown in these curves was obtained from flights of aircraft 057 and 058 in the cold free air temperatures in the area of the Far East operating base. The data from aircraft 058 displayed in Figures 17 and 17A are a case in point where both the aircraft and engine performance are considerably above their respective predicted values due to the very cold free air temperatures and the fact mentioned previously that this engine (S/N 612627) provides relatively good performance (i.e. above specification) even on a standard day.

/s/
[redacted] 25X1A
PSD/R&D/OSA

Attachments
As stated