The Development and Use of a Flight Optimization System Model of a C-130E Transport Aircraft

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Abstract

The Systems Analysis Branch at NASA Langley Research Center conducts a variety of aircraft design and analyses studies. These studies include the prediction of characteristics of a particular conceptual design, analyses of designs that already exist, and assessments of the impact of technology on current and future aircraft.

The Flight Optimization System (FLOPS) [Ref. 1] is a tool used for aircraft systems analysis and design. A baseline input model of a Lockheed C-130E was generated for the Flight Optimization System. This FLOPS model can be used to conduct design trade studies and technology impact assessments. The input model was generated using standard input data such as basic geometries and mission specifications. All of the other data needed to determine the airplane performance is computed internally by FLOPS. The model was then calibrated to reproduce the actual airplane performance from flight test data. This allows a systems analyzer to change a specific item of geometry or mission definition in the FLOPS input file and evaluate the resulting change in performance from the output file.

The baseline model of the C-130E was used to analyze the effects of implementing upper wing surface blowing on the airplane. This involved removing the turboprop engines that were on the C-130E and replacing them with turbofan engines. An investigation of the improvements in airplane performance with the new engines could be conducted within the Flight Optimization System. Although a thorough analysis was not completed, the impact of this change on basic mission performance was investigated.

Introduction

The Systems Analysis Branch at NASA Langley Research Center is involved in the design and analysis of new aircraft concepts and the assessment of technology impacts on existing and future aircraft. One of the resources used in these studies is a library of computer models, or specifically Flight Optimization System (FLOPS) models, of existing aircraft. These models are used by engineers to evaluate new ideas and theories for improving aircraft performance through the use of existing aircraft . This method produces reasonably accurate results in a timely and cost effective manner which can be used to identify areas for future in-depth research such as flight tests.

A FLOPS baseline model of a Lockheed C-130E was generated as an addition to an existing library of aircraft models in the Systems Analysis Branch. The model can be used to evaluate changes in basic mission sizing and performance resulting from changes in the airplane configuration, weights, aerodynamics, or propulsion system. The model consists of a series of input and output files, compatible with the Flight Optimization System, that closely reproduce the actual airplane characteristics. FLOPS baseline development and associated derivative studies were performed using the X-Windows based X-FLOPS tool found on the Systems Analysis Branch's Silicon Graphics workstations.

The C-130E baseline model was also used to conduct some limited design trade studies and technology impact assessments through the implementation of an upper surface blowing concept. The idea was to use turbofan engines to augment the air flowing over the upper surface of the wing thereby increasing lift. This concept would decrease the runway length required by this airplane for takeoff and landing and improve its low speed flight characteristics. Unfortunately, no detailed data was obtained for takeoff and landing for the actual C-130E. For that reason, only the basic improvements in mission performance with the new engines and upper surface blowing concept could be investigated.

Approach and Methodology

The C-130E is a special operations military transport powered by four Allison T56 turboprop engines. The baseline model for the airplane was compiled by using available data on the existing C-130E. The sources of airplane information included the Standard Aircraft Characteristics Chart [Ref. 2], a MIL-STD-1374 Group Weight Statement [Ref. 3], Jane's All the World Aircraft [Ref. 4], the Propulsion Summary Characteristics Chart for the Allison T56 turboprop engines [Ref. 5], and other existing aerodynamic and thrust data for the airplane.

The source data was broken into four categories before it was put into the input file. These categories were geometry, weights, aerodynamics, and propulsion performance, also referred to as the engine deck. All of the known information from these categories except aerodynamics was used to put together the input file for the initial model. It was intended that, using this information, FLOPS would compute the aerodynamics internally. Initial FLOPS executions were made to determine how the output for the model would compare with the real data. The FLOPS model was then calibrated to reproduce the actual airplane mission performance and other performance constraints. Comparisons were made between the internally computed aerodynamic data and the existing aerodynamic data to ensure that the FLOPS model was reasonable. After the model was calibrated, the real weight data was taken out of the input file. The model was then recalibrated so that FLOPS generated all of the weights and aerodynamics internally given the specific C-130E airplane geometry and engine deck. This calibrated model along with the output made up the baseline model.

The concept behind the baseline model is that most of the airplane data is generated internally within the FLOPS program driven by key aspects of the airplane design. If design changes are made, the program will automatically account for all of the corresponding changes due to the initial design change. This feature is what allows the engineer to investigate the impacts of new ideas and technology on the performance of an existing airplane. Other derivatives of the baseline model were also made to allow investigations involving more isolated changes such as replacing the current engines with more efficient ones. With the original baseline model, changing the engines would change the design of the wings and many other components on the airplane. These results would not properly reflect the design change made since it was not intended to change the wing and other equipment just because the engines were changed. Derivative models allow for changing specific airplane components while leaving all of the other components untouched.

Both design trade studies and technology impact assessments were conducted for the implementation of the upper surface blowing concept on the baseline model. The implementation of this concept involved an engine change as described in the paragraph above. The approach taken was to change just the engines on the airplane without changing any other aircraft structure or systems. High by-pass ratio turbofan engines with approximately the same static thrust rating as the Allison T56 turboprops were selected for this investigation. The engines selected were the General Electric TF34 engines rated at 9000 pounds sea level static thrust. Since only limited data was available for takeoff, landing, and other low speed flight characteristics for the C-130E, only the major impacts of the new engines on basic mission performance--range, speeds, and altitudes--were examined. This investigation would be considered a design trade study.

The General Electric TF34 engines chosen for the upper surface blowing concept were relatively old engines. New technology, if implemented on these engines, could reduce fuel consumption and increase thrust. Using the new derivative model, the effects of the newer technology on the performance of the engines were also investigated. The change in engine performance directly affected the airplane performance. This would be an example of a technology impact assessment.

Results

The baseline model was validated using a number of performance constraints and parameters describing the basic design mission. These parameters were limited to a deviation of 5% from the actual value. These parameters along with their actual values and FLOPS baseline model values are shown in Table 1.

Table 1: Validation of the FLOPS Baseline Model

Aircraft Parameter	C-130E (Actual)	FLOPS Baseline Model
Gross Weight for 2000 n.m. range	152,914 lb	152,723 lb
Rate of Climb at S.L.	1630 fpm	1659 fpm
Rate of Climb at S.L. OEI	1000 fpm	951 fpm
Average Cruising Speed	287 kts	279 kts
Initial Cruising Altitude	21,200 ft	22,300 ft
Final Cruising Altitude	37,700 ft	37,000 ft
First Landing Weight	134,766 lb	132,706 lb
Total Mission Time	7.2 hrs	7.37 hrs
Max Velocity at Combat Weight (90087)	325 kts	319 kts
Combat Speed	301 kts	303 kts
Combat Ceiling	34,100 ft	34,400 ft
Service Ceiling at Combat Weight	36,750 ft	36,400 ft
Service Ceiling OEI at Combat Weight	30,400 ft	31,900 ft

The baseline model can be further validated by examining Figures 1 and 2. Figure 1 shows a comparison of the actual C-130E drag polars and the drag polars computed internally with the FLOPS model. These drag polars reflect the best available for constraint matching. The maximum error between the two curves is 9%. This was the smallest overall error achieved between the two polars while maintaining the 5% error constraint on performance. There may be an inaccuracy in the engine deck which might have caused the discrepancy between the performance matching and the drag polars matching. It was considered more important that the performance results match than the drag polars in generating the baseline model; therefore, the error in the drag polars was accepted. Figure 2 shows the payload-range diagram for both the actual C-130E and the baseline model. These diagrams match very closely, indicating that the model performance very closely reproduced that of the real airplane.

The results of the implementation of the upper surface blowing concept indicated an small overall improvement in performance. This was the expected result, but without the necessary takeoff, landing, and low speed fight characteristics data for the C-130E, the total impact of upper surface blowing on the airplane could not be determined at this time. With the replacement of the turboprop engines with turbofans, an increase in speed and altitude and subsequent operational mission improvement was observed. A summary of the improvements in performance with the addition of the upper surface blowing is presented in Table 2.

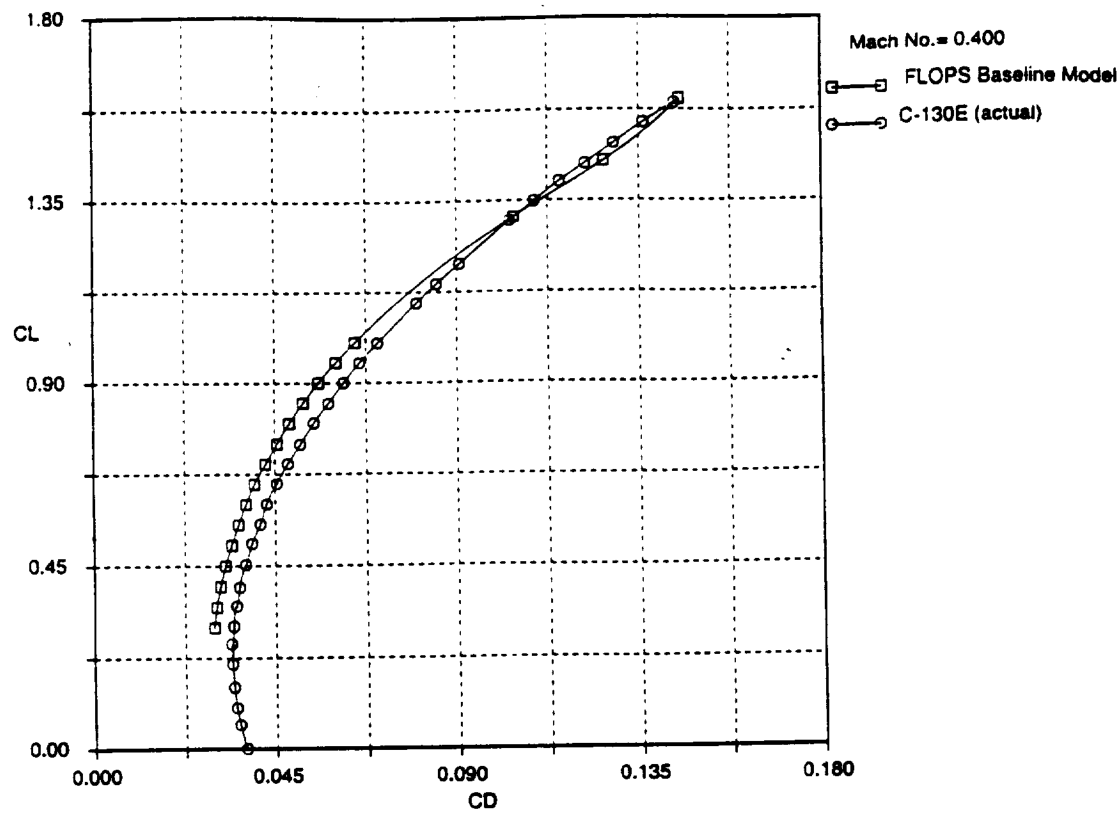

Figure 1: C-130E AERO POLAR PLOT - ALTITUDE = 0

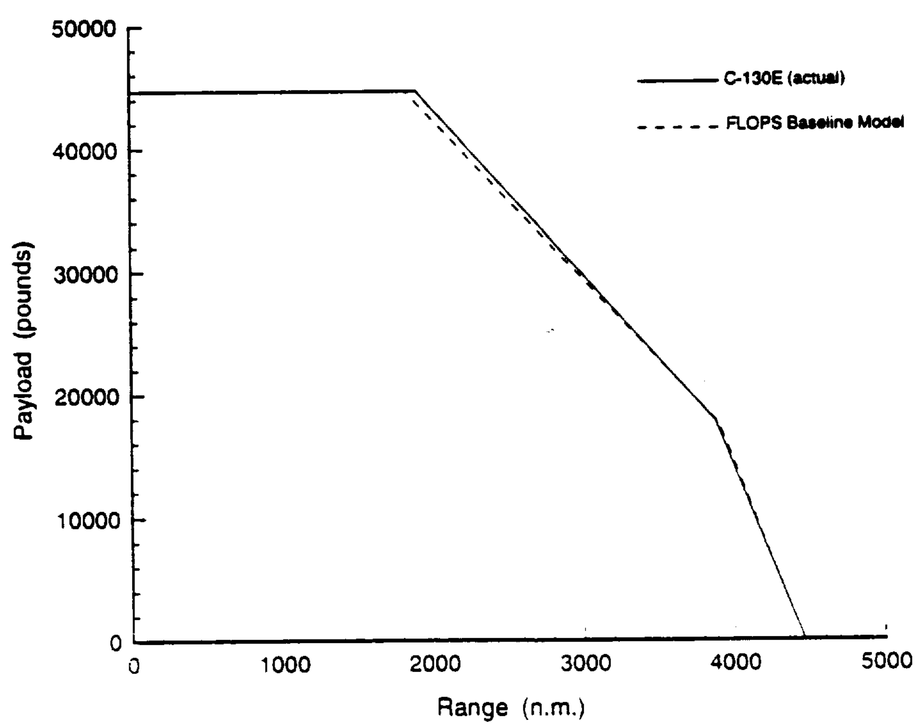

Figure 2: Payload-Range Diagram

Table 2: Improvements in Performance with Upper Surface Blowing

Airplane Performance Parameter	Change in Performance
Total Mission Time (2000 n.m. range)	-42 min
Max Rate of Climb at S.L.	+300 fpm
Max Rate of Climb at S.L.	+360 fpm
Max Velocity at 18,000 ft	+34 kts
Combat Velocity at 34,600 ft	+39 kts
Combat Rate of Climb at 34,600 ft	+215 fpm
Service Ceiling	+4000 ft
Combat Rate of Climb at S.L.	+740 fpm
Cruise Altitude (average)	+4000 ft
Cruise Velocity (average)	+29 kts
Operating Weight Empty	-8700 lb
Fuel Consumed	+6000 lb

The results above were computed using the baseline reference gross weight to obtain a meaningful comparison. The total mission time was based on a gross weight sized for a range of 2000 n.m with the GE TF34 engines. It is evident that the turbofans showed some marked points of improvement in airplane performance. The turbofans did consume more fuel which had a significant impact on range. The range improved slightly for heavy payload weights due to the decrease in operating empty weight. As the payload weight went down, the range did not grow as fast as with the Allison T56 engines due to the increased fuel consumption. This trend can be seen in the payload-range diagram contained in Figure 3.

Since the General Electric TF34 engine was designed in 1972, two decades of significant engine technology improvements would make the engine more efficient and powerful. Assessing the impact newer technology would have on the engine/aircraft performance, the FLOPS model with the TF34 engines was used to investigate higher engine thrust ratings and lower fuel consumptions. Figure 3 shows the payload-range diagrams for several conditions. The conditions include the baseline C-130E model and the derivative model with the TF34 engines at their original thrust rating and thrust rating increases. It can be seen that increasing the power output of the engines, or increasing thrust, does not have a significant effect on the airplane range. The airplane performance otherwise did increase with higher thrust.

Figure 4 shows the effects of reducing the engine fuel consumption. Reduction in fuel consumption does have a significant effect on range. The reduction in fuel flow did not make any significant improvements in other aspects of airplane performance, though. This figure also shows the possible effects of year 2005 technology. Improvements in materials and manufacturing will allow not only large fuel consumption reductions, but also significant reductions in thrust-to-weight ratios. This 2005 technology is represented in Figure 4 by a 50% reduction in fuel flow and 15% increase in thrust-to-weight ratio.

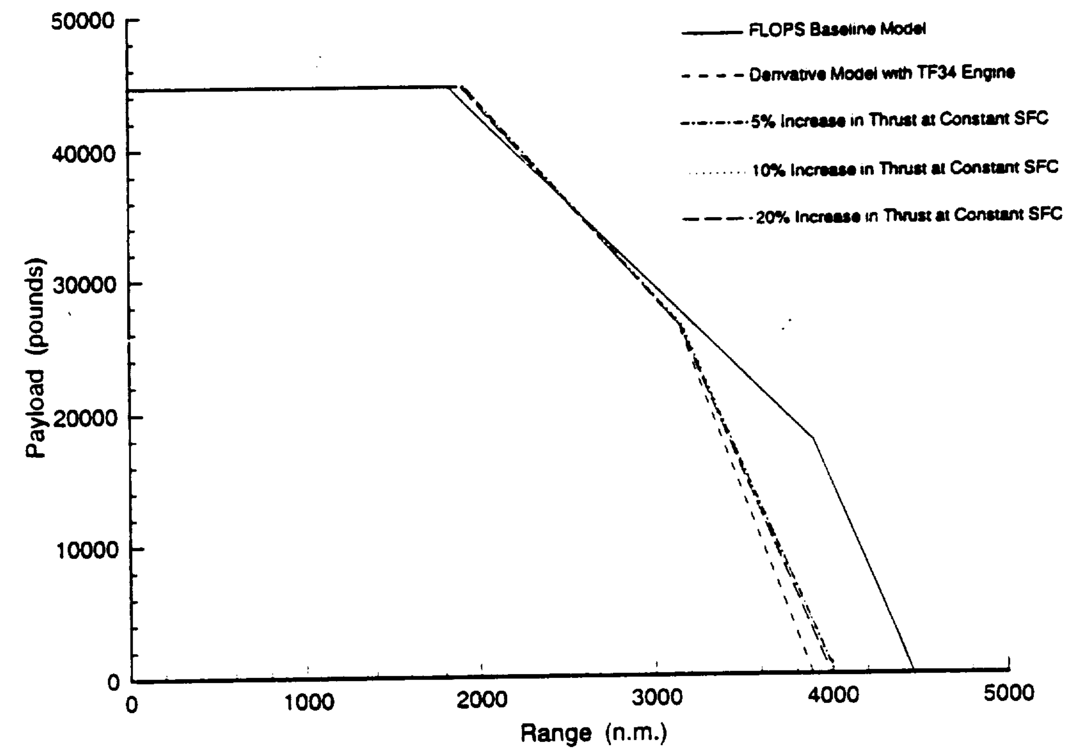

Figure 3: Payload-Range Diagram for Increased Thrust with the TF34 Engine

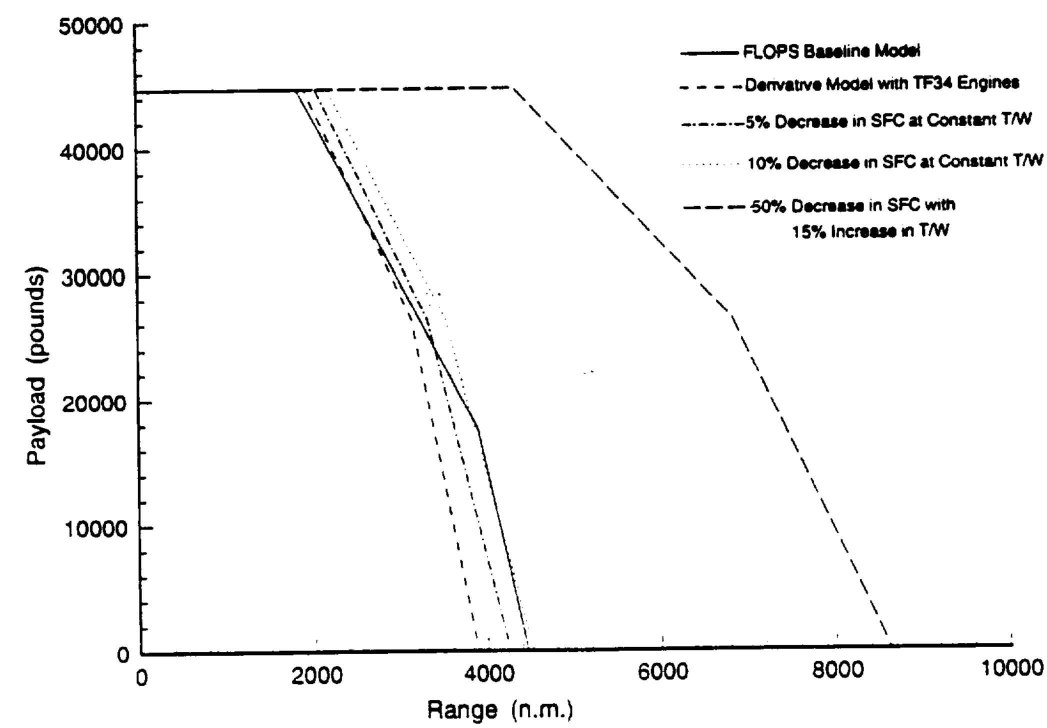

Figure 4: Payload-Range Diagram for Decreased Fuel Flows with the TF34 Engine

Conclusions

The baseline performance model of the C-130E was created for the Flight Optimization System. The model was calibrated against known data to reproduce the actual airplane performance. Variations of the baseline model were used to examine the implementation of an upper wing surface blowing concept using high by-pass ratio turbofan engines. Variations of the baseline model were also used to examine the impact of new technology on the engine/aircraft performance.

The upper surface blowing concept had mixed benefits to basic mission performance. The addition of turbofan engines to the aircraft increased cruising speeds and altitudes and reduced the airplane empty weight. Unfortunately, the turbofan engines also consumed more fuel. For full cargo missions, the range increased slightly due to the advantage of the lighter operating empty weight. As cargo weights went down and range increased, the higher fuel consumption negated the benefit of the reduction in empty weight and range performance decreased significantly. The application of technology to increase engine thrust did little to affect airplane range, although it did improve other performance characteristics. Technology to reduce fuel consumption had a significant impact on aircraft range while leaving other aircraft performance characteristics basically unchanged.

References

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