MAE 159 Midterm Aircraft Sizing Report

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Contents

1 Introduction

This report consists of a study on the cost and performance optimization for two subsoinc commercial transport aircraft, one non-stop aircraft and one one-stop aircraft. Herein, the reader will find a summary of the methods used and the data generated from an iterative python script which uses standard, well-defined aircraft design methods to exactly meet the design specifications. Various parameters, including the aspect ratio, the airfoil type, the wing sweep angle, and the seating configuration, were systematically varied to determine the optimum design parameters for each aircraft. In the conclusion of the report, the optimum aircraft design parameters will be given as well as a summary of why the design was chosen, and which of the two aircraft may suit the customer's needs the best.

2 Design Specifications

As mentioned prior, two aircraft with distinct given design requirements, were considered in this design study. Both aircraft are required to carry 225 passengers and complete a 7400 nautical mile journey. The first larger aircraft must complete the journey without any stops. The second smaller aircraft must complete the journey with one-stop, giving the airplane a required range of 3700 nautical miles. The complete set of given design specifications are listed in tables 1 and 2 below. For both aircraft, takeoff conditions were assumed to be at sea level on a hot day with an air temperature of $84°F$.

Non-stop Aircraft	
Design Specification:	**Parameter Value:**
Number of Passengers	225
Weight of Cargo	6,000 lbs
Still Air Range	7,400 nmi
Takeoff Field Length	10,500 ft
Landing Approach Speed	140 kts
Fuel Destination Payload	35%
Cruise Mach Number	0.85
Initial Cruise Altitude	35,000 ft

One-stop Aircraft	
Design Specification:	**Parameter Value:**
Number of Passengers	225
Weight of Cargo	3,000 lbs
Still Air Range	3,700 nmi
Takeoff Field Length	6,000 ft
Landing Approach Speed	130 kts
Fuel Destination Payload	0%
Cruise Mach Number	0.80
Initial Cruise Altitude	35,000 ft

Table 1: Given Design Specifications.

3 Design Analysis

The object of this section is to perform an analysis for both aircraft and determine the optimized specifications for the design parameters. An iterative python script was developed with allowable user input for user-selectable design parameters to make calculations of direct operating cost (DOC), weight, drag, and other aircraft performance characteristics easy, fast, and repeatable.

3.1 Direct Operating Cost versus Aspect Ratio and Wing Sweep Angle

The aspect ratio describes the ratio of the aircraft's wingspan to its mean aerodynamic chord length. A small aspect ratio describes a short and wide wing whereas a larger aspect ratio describes a long and narrow wing planform (1). The wing aspect ratio is an important factor in determining the available lift of the aircraft, the weight of the aircraft, and the induced drag during flight. For a typical jet transport aircraft, Schaufele gives an aspect ratio range of 7.0 to 9.5 (3), as such, this formed the basis for design selection. Aspect ratios in steps of 0.1 were considered from 6.0 to 12.0 during this study. The method for comparison will be the resulting DOC per passenger, per mile. Figure 1 shows the aspect ratio versus the DOC with curves of fixed sweep angle for both the short range and long range aircraft. The fixed sweep angle curves are shown in steps of 1 degree. Each plot in 1 shows a total of 1800 discrete aircraft designs. All aircraft designs in this analysis utilized two JT9D engines and had one aisle with six abreast for the seating configuration.

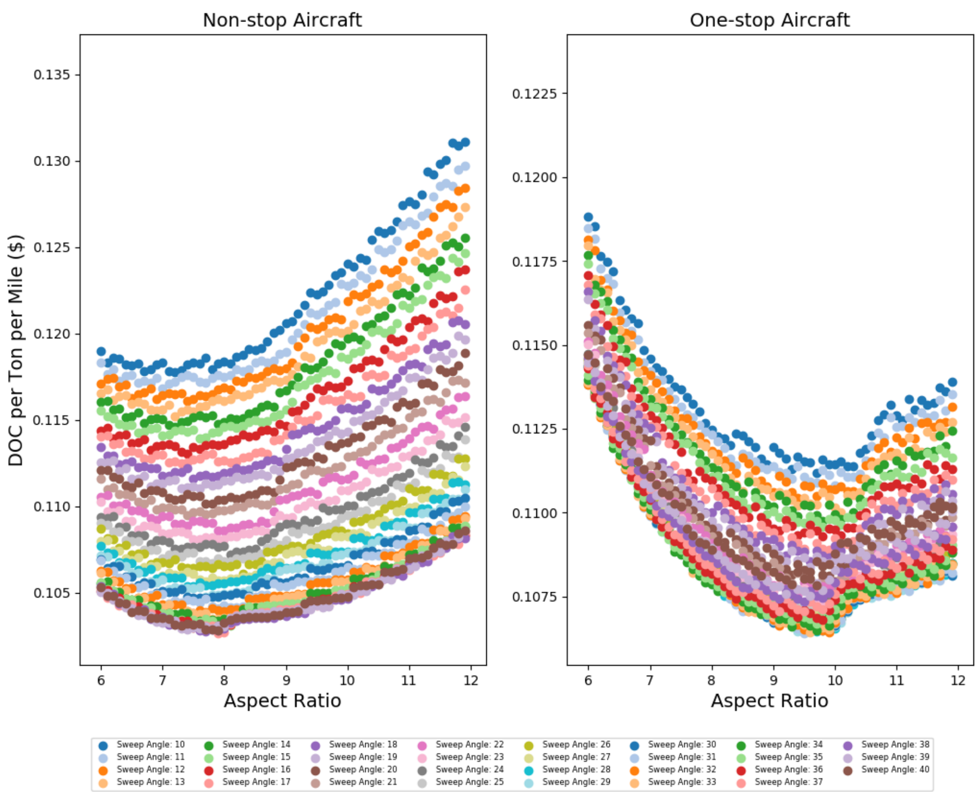

Figure 1: Direct operating cost, per ton, per mile plotted against aspect ratio for the non-stop and one-stop aircraft at different wing sweep angles.

From figure 1, the optimized aspect ratio can be determined by finding the range at which the minimum value occurs. Due to the number of unique aircraft designs considered in this section of the study, a zoomed in version is presented in 1. The nonstop aircraft plot is zoomed in on the 7.0 to 8.2 aspect ratio range and the one-stop aircraft plot is zoomed in on the 9.0 to 10.2 aspect ratio range.

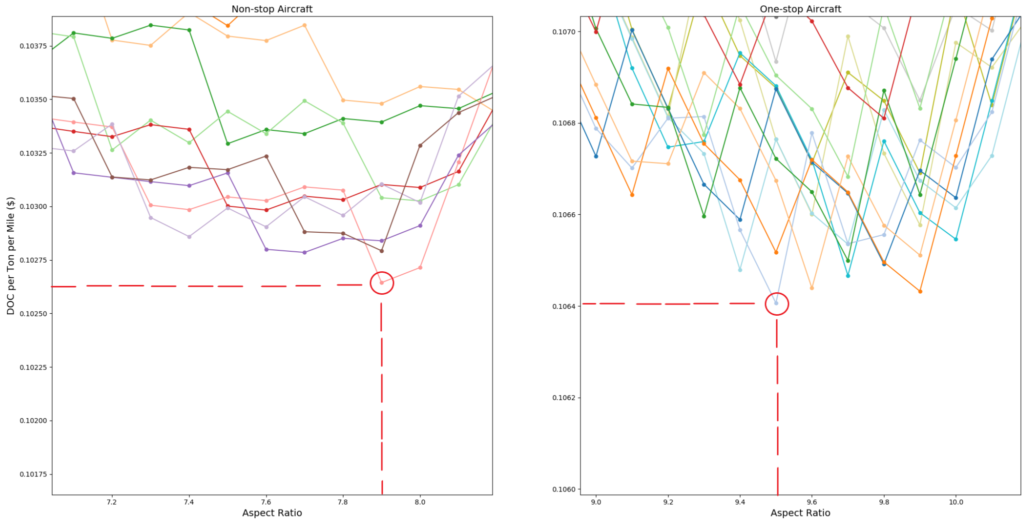

Figure 2: Zoom of the direct operating cost, per ton, per mile plotted against aspect ratio for the non-stop and one-stop aircraft at different wing sweep angles.

From this analysis, it is evident that for the non-stop aircraft, the optimized aspect ratio is 7.9 with a wing sweep angle of 37 degrees. For the one-stop aircraft, the optimized aspect ratio is 9.5 with a wing sweep angle of 31 degrees. This corresponds to a direct operating cost, per ton, per mile of $0.1064 and $0.1026 for the one-stop and nonstop aircraft respectively. The rest of the sections within section 3 will be based off of the control values found in this section of the report, using conventional technology and a seating configuration of one aisle and six seats abreast.

3.2 Weight versus Aspect Ratio and Wing Sweep Angle

Now that the most efficient plane in terms of cost to operate has been found, it is of interest to look at the weight of each discrete aircraft design generated in section 3.1. Figure 3 plots the takeoff weight of the aircraft in pounds versus the aspect ratio using fixed lines of sweep angle. The plots in this figure show a much more dramatic divergence from the optimum value than the direct operating cost plots. The minimum weight values occur near the range of aspect ratios for the lowest direct operating cost.

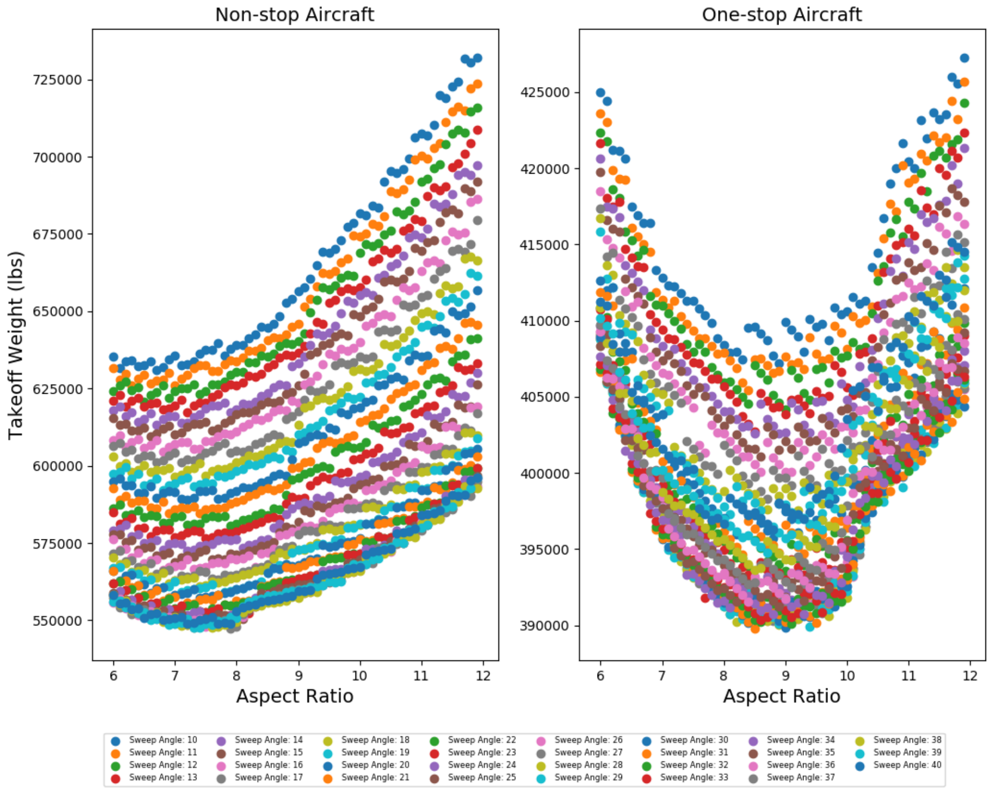

Figure 3: Aircraft takeoff weight plotted against sweep angle for the non-stop and one-stop aircraft at the optimized aspect ratios.

3.3 Advanced Technology

Modern technology and manufacturing advancements has allowed for the use of more exotic airfoil shapes and airframe materials that previous heritage aircraft could not take advantage of. Regarding airfoil selection, the advent of supercritical airfoils has been cited to improve aircraft fuel efficiency and thus lower the direct operating cost of the aircraft. The Boeing 757 and 767, developed during the 1980s were some of the first commercial aircraft to use this technology (2). However, these airfoils types are comprised of more complicated compound curves which presents added complexity in the manufacturing process, driving up initial cost of the aircraft however, the decrease in operational costs of the aircraft exceeds the initial procurement cost increase of the aircraft.

The second advanced technology considering during the design process was the implementation of composites for the airframe materials. Airframes have typically been composed of various aluminum alloys which presents a strong yet lightweight option. However, recent advancements in materials engineering has allowed for reliable implementation of composite layups, which are lighter and stronger than the aluminum alternative. However, the process to form structures from composites is complicated and if not performed properly, the composite structures may exhibit delamination. Performing the process correctly is expensive and time consuming, thus driving up the initial procurement costs of the aircraft using this technology. However, the savings in direct operating costs may offset this initial procurement price.

Figure 4 plots the direct operating cost of the aircraft using the optimized aspect ratio and wing sweep angle found in section 3.1, with the implementation of different technology improvements. Figure 5 plots the takeoff weight of the aircraft with different technologies.

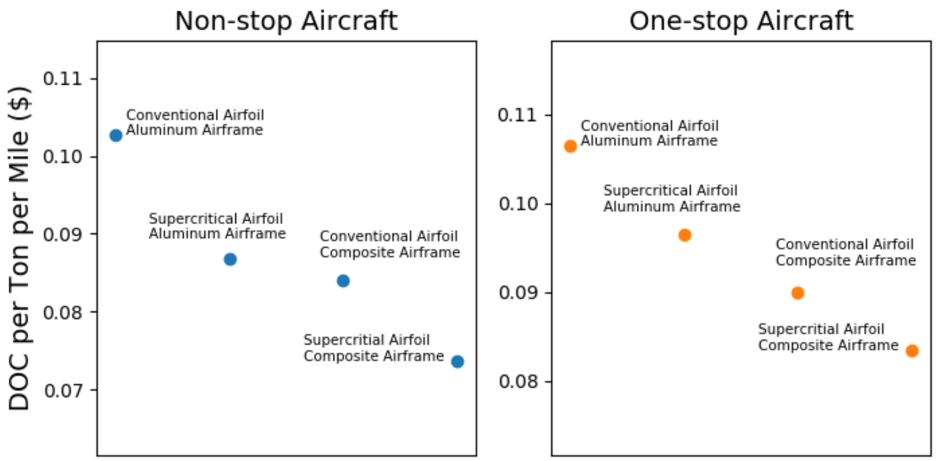

Figure 4: Direct operating cost, per ton, per mile for the optimal aircraft configuration using different technologies.

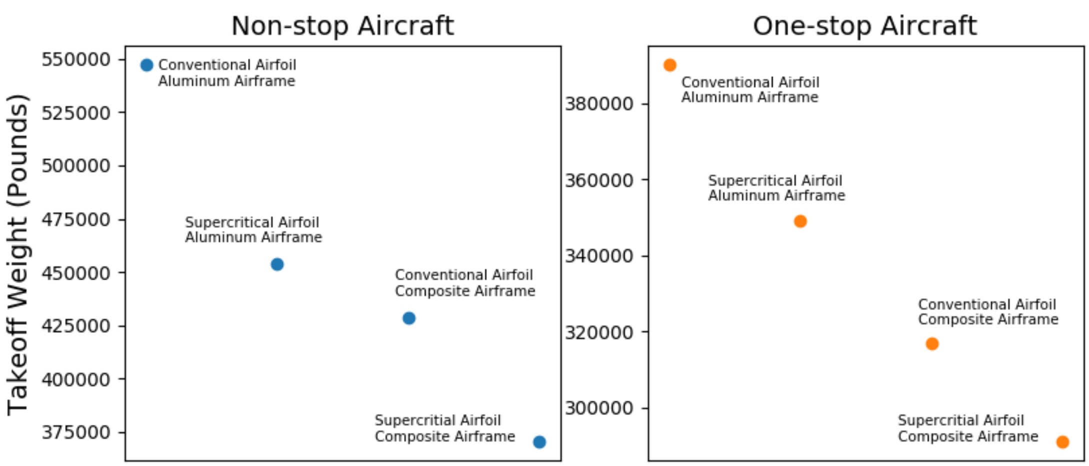

Figure 5: Takeoff Weight for the optimal aircraft configuration using different technologies.

It is clear that both technologies, supercritical airfoils and composite structures, reduce the direct operating cost. Although using a supercritical airfoil may produce a different optimized aspect ratio and sweep angle, this effect was not considered in this studyUsing them together drives down the operating cost and weight of the aircraft dramatically.

3.4 Aircraft Seat Configuration

The aircraft seat configuration can also be varied in the number of aisles that run the length of the fuselage, and the number of seats abreast. In this case, the main metric of comparison will be the direct operating cost. For this study, the optimized aspect ratio and both supercritical airfoil technology and composite technology has been applied to the aircraft design. In the previous sections, the standard configuration of one aisle and six passengers abreast was considered. These results are plotted in figure 6.

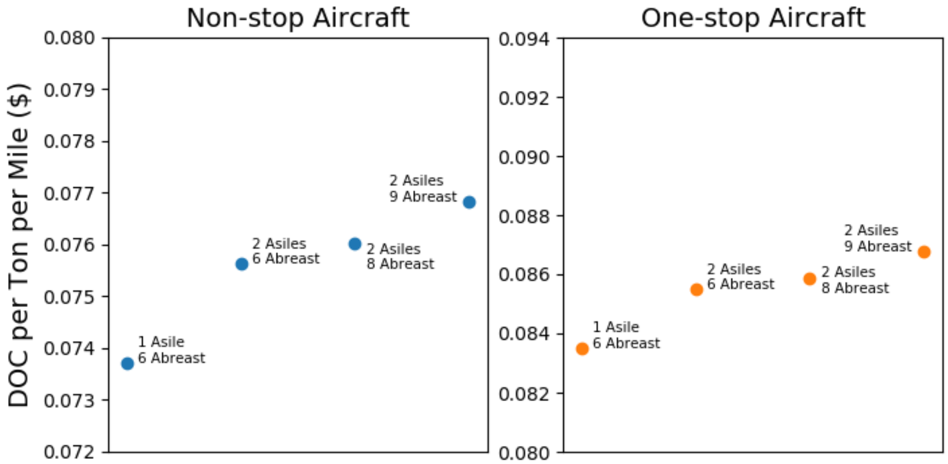

Figure 6: Direct operating cost, per ton, per mile for the optimal aircraft configuration using different seating configurations.

From this study, it is evident that when holding the number of aisles constant, increasing the number of passengers abreast leads to a higher direct operating cost. Additionally, it is clear that the one aisle, six abreast configuration had a lower direct operating cost for both aircraft than any of the two aisle configurations. However, the two aisle configuration has been found to have an advantage over a one aisle configuration in the fact that passengers are able to load and unload from the aircraft more quickly, significantly reducing the down time required when at the airports. For aircraft that may be making shorter flights, such as the one-stop aircraft in this study, it may be more beneficial to use the two-aisle configuration despite the higher direct operating cost found in this study. The increased loading and unloading efficiency was not taken into account in the direct operating cost estimation used in this study.

3.5 Number of Engines

The final design consideration was the number of engines. Figure 7 plots the direct operating cost for a 1 aisle, 6 abreast airplane using the optimized aspect ratio and wing sweep angle, with both advanced technologies applied. It is clear from the plot that increasing the number of engines dropped the direct operating cost; for the nonstop aircraft, the optimum number of engines was three in terms of the direct operating cost. As with the other sections of the report, increasing the number of engines will increase the initial procurement cost, which was not considered in the direct operating cost calculation.

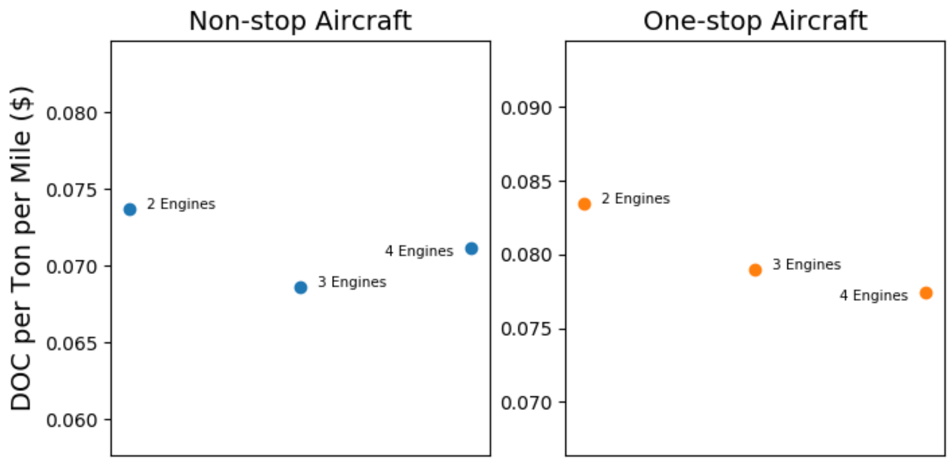

Figure 7: Direct operating cost, per ton, per mile for the optimal aircraft configuration, using 1 aisle and 6 abreast, with different engine count.

4 Summary and Conclusion

This section will summarize the results of the non-stop and one-stop aircraft design studies discussed in detail in the previous sections herein. Recommendations shall be made as to which aircraft may suit a given customer's needs the best.

4.1 Final Aircraft Design Specifications

The table below lists the final optimized specifications of the non-stop and one-stop aircraft.

Non-stop Aircraft	
Specification:	**Optimized Value:**
Sweep	37 deg
Aspect Ratio	7.9
Airfoil Type	Supercritical
Wing Area	2196 ft^2
Wing Span	132 ft
Number of Aisles	1
Number of Seats Abreast	6
Fuselage Diameter	14.4 ft
Fuselage Length	191 ft
Number of Engines	4
Structure Type	Composite
Takeoff Weight	330085 lbs
Fuel Weight	130591 lbs
DOC	0.071 $/ton/mile

One-stop Aircraft	
Specification:	**Optimized Value:**
Sweep	31 deg
Aspect Ratio	9.5
Airfoil Type	Supercritical
Wing Area	2052 ft^2
Wing Span	139 ft
Number of Aisles	2
Number of Seats Abreast	6
Fuselage Diameter	14.7 ft
Fuselage Length	174 ft
Number of Engines	2
Structure Type	Composite
Takeoff Weight	299275 lbs
Fuel Weight	91869 lbs
DOC	0.085 $/ton/mile

Table 2: Final aircraft sizing specifications.

4.2 Payload Range

This section shows the payload range chart. This chart plots the range for each optimized aircraft can fly given varying payloads.

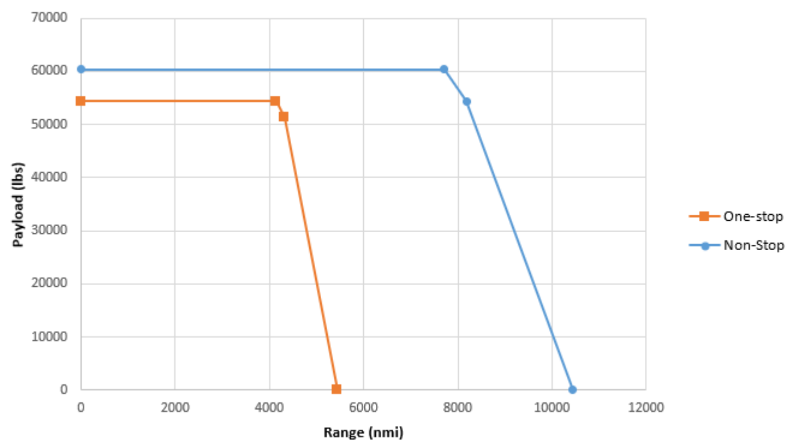

Figure 8: Payload range plotted against the range.

4.3 Recommendations

The final aircraft design specifications were chosen based on optimizing the minimum direct operating cost, providing appealing options for the customers needs, and creating a safe aircraft. The non-stop aircraft utilized four engines to minimize the direct operating cost and increase redundancy in case one of the engines failed on the long flight. The one-stop aircraft utilized only two engines, but used a two aisle seating configuration. This configuration was chosen for the smaller airplane for its ability to load and unload passengers more quickly, thus decreasing the idle time at airports and increasing the maximum number of flights than may be conducted on a given day.

For long flights, the non-stop aircraft presents the better option. It uses less fuel to reach the destination than two of the one-stop flights (130591 lbs of fuel versus 183738 lbs of fuel). Additionally, the long range aircraft is able to carry more cargo and has the lower direct operating cost, per ton, per mile.

5 References

1. Hall, Nancy. (2018). Wing Geometry Definitions. NASA Glenn Research Center.

2. Roeseler, W. G., et al. (2007). Composite Structures: The First 100 Years. 16TH INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS.

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