

Investigation on the Benefit and Feasibility of Applying Formation Flight to Civil Transport Aircraft

Potenzial- und Machbarkeitsanalyse der Anwendung des Formationsflugs
auf zivile Luftverkehrsflugzeuge

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vorgelegt von

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Abstract

TAKING advantage of the upwash effect of the leading aircraft, formation flight has the potential to be adopted for civil transport aircraft applications to save fuel consumption, emissions and also costs by drag reductions. In the scope of this dissertation, the author has carried out systematic investigations on formation flight benefits and feasibility from components level, overall aircraft level to fleet level.

A potential flow solver has been adapted for the formation flight (FF) induced drag reduction estimation. Special attention has been paid to the lift coefficient conditions of leading and trailing aircraft. The calculated FF induced drag results have been compared and validated with wind tunnel measurements and other simulation results, which show satisfactory agreement. A continual trailing edge variable camber method has been employed for FF lateral trimming and cruise flight aerodynamic optimization. To capture the full configuration aerodynamic features, as well as other overall aircraft performance, such as fuel consumptions, emissions and costs, the method of calculating FF induced drag polar has been integrated into the in-house overall aircraft design and optimization environment. In addition, a FF passenger comfort estimation method has also been incorporated in the framework, which accounts for the impact of FF force and moment gradients and the atmospheric turbulence. The overall aircraft results are utilized to create surrogates model for FF fleet impacts investigation.

In the aircraft component level study, the application of variable camber shows advantages in aerodynamic benefits for FF trailing aircraft in comparison with aileron trimming. In the overall aircraft level, case studies on two medium range and two long range transport aircraft in FF indicate double-digit percentage fuel burn savings. Besides, fuel planning strategies for formation trailing aircraft give insight into the achievable fuel savings and safety compromise. According to the passenger comfort evaluation results, FF slightly increases the vibration total value, but does not degrade the comfort category. For fleet level analysis, significant fuel savings can be obtained on the basis of two aircraft formation flight with real world operation constraints, such as scheduled departure time, flight frequencies, distance penalties, etc. The whole airline FF application also shows that 2-5% total fuel burn savings can be expected.

Zusammenfassung

IM Zuge dieser Arbeit hat der Autor systematische Untersuchungen der mit Formationsflügen verbundenen Vorteile sowie der Realisierbarkeit auf Komponenten-, Flugzeug- und Flottenebene durchgeführt.

Ein leistungsstarker Strömungslöser wurde für die Abschätzung der durch Formationsflug erreichten Reduzierung des induzierten Widerstandes eingeführt. Die errechneten Ergebnisse des induzierten Widerstandes wurden mit Hilfe von Messergebnissen aus dem Windkanal und anderen Simulationen verglichen und validiert. Sowohl für die laterale Trimmung, als auch für die aerodynamische Trimmung in Formationsflugkonstellation wurde eine Methode mit kontinuierlicher Hinterkante und variabler Wölbung angewendet. Um die vollständigen aerodynamischen Merkmale und weitere Flugzeugleistungen wie Treibstoffverbrauch, Schadstoffemissionen und Kosten bei der Berechnung der induzierten Widerstandspolaren berücksichtigen zu können, wurde die Methode in die Flugzeugentwurfsumgebung integriert. Darüber hinaus wurde ein Modell zur Abschätzung des Passagierkomforts in die Umgebung eingeführt, um die bei Formationsflügen hervorgerufenen Kräfte, Momentengradient sowie atmosphärischen Turbulenzen einzubeziehen. Die Ergebnisse auf Flugzeugebene werden für die Erstellung von Ersatzmodellen verwendet.

Für das in der Formationsflugkonstellation folgende Flugzeug konnte mittels Durchführung von Studien auf Komponentenebene nachgewiesen werden, dass die Anwendung einer variablen Wölbung gegenüber der Querrudertrimmung aerodynamische Vorteile aufweist. Auch auf Flugzeugebene konnten anhand von weiteren Studien mit je zwei Mittel- und Langstreckenflugzeugen in Formationsfluganordnung zweistellige prozentuale Einsparungen in Bezug auf den Treibstoffverbrauch aufgezeigt werden. Zugleich geben Treibstoffplanungsstrategien für das folgende Flugzeug Aufschluss über eine mögliche Reduzierung des Treibstoffverbrauchs sowie über Sicherheitskompromisse. Den Ergebnissen der Passagierkomfortuntersuchungen zufolge, führen Formationsflüge zwar zu einem leichten Anstieg der Vibrationswerte, doch wird der Komfortfaktor nicht wesentlich beeinflusst. Unter Beziehung realer Flugbetriebsrestriktionen, wie beispielsweise planmäßige Abflugzeiten, Anzahl der Flugdurchführungen, Abstände etc. konnten auf Flottenebene anhand von Formationsflügen mit insgesamt zwei Flugzeugen 2-5% Treibstoffeinsparungen erzielt werden.

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