TECHNICAL NOTE

AIRBORNE SEPARATION ASSISTANCE DURING LANDING - AN APPROACH FOR AUTOMATION

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Abstract

Self-spacing and Required-Time-of-Arrival (RTA) concepts are now being developed to support future Air Traffic Management (ATM) systems. Among many types of separation methods, distance based separation assumes importance form safety point of view. The present study is an attempt to analyze approach proposed by EUROCAE and extend the same for development of guidance laws in the form of acceleration commands instead of speed commands. Objective is to realize an effective implementation of the guidance laws in the Thrust Management Function of onboard Flight Management System. Simulation studies are presented involving actual flight responses for the lead aircraft during terminal phase.

Nomenclature

ADS-B = Automatic Dependent Surveillance - Broadcast
ASAS = Airborne Separation Assistance System
AT = Auto Throttle
ATC = Air Traffic Control
ATD = Along Track Distance
ATM = Air Traffic Management
DS = Desired Spacing
FAF = Final Approach Fix
FMS = Flight Management System
GS = Ground Speed
IAF = Initial Approach Fix
IM = Interval Management
m = Mass of Aircraft
OGS = Ownship Ground Speed
RTA = Required Time of Arrival
SE = Spacing Error
TC = Time Constraint
TGS = Target Ground Speed
TMA = Terminal Maneuvering Area

Introduction

As observed in the literature review, in order to bring the arrival rates back toward non-CDA rates, self-spacing and Required-Time-of-Arrival (RTA) concepts are now being developed to support CDA procedures. Some of the Self Spacing concepts which are being explored by various research activities are as follows [Ref.1-4] are Constant Distance Spacing, Constant Time Spacing and Constant Time delay spacing. Constant distance spacing, which is also known as station-keeping, is considered as the most basic form of airborne self-spacing. Using this technique, the own aircraft maintains a fixed distance interval with respect to its leading aircraft. Constant time spacing is also a very basic form of airborne self-spacing, in which the aircraft maintains a fixed time interval with respect to the leading as they move forward. The third form of separation is the Constant time delay spacing, which was developed by NASA as an improvement to the other two systems. The concept is also known as time-history spacing. In this approach, each successive aircraft attempts to fly the speed profile of the aircraft which is to be followed along the flight path. As part of the present study, the approach proposed by EUROCAE [Ref.5, 6] is taken up for analysis and its modification to include acceleration command as guidance command instead of velocity command in order to enable implementation through onboard Flight Management System (FMS).

Modeling and Analysis

Approach of EUROCAE

The approach involves determining suggested speed to be followed by the own aircraft in order to maintain separation with respect to the lead aircraft along the flight

Paper Code : V68 N2/925-2016. Manuscript received on 07 Oct 2015. Reviewed, revised and accepted as a Technical Note on 08 Mar 2016

path. This method involves determination of Separation Error (SE), based on the prevailing distance of separation and on consideration of certain minimum Desired Separation (DS) to be maintained for safety purposes. The concept implies ADS-B capability for the both the aircraft and in addition storing of the time history of the lead aircraft by the own aircraft. Own aircraft is assumed to follow the speed profile of the lead aircraft. Incremental speed is then computed which can be displayed in the cockpit as guidance information for the pilots or can be fed to Auto throttle system for adjustment of aircraft speed. Flight path on horizontal plane, as shown in Fig.1 is considered for this analysis.

Let the lead and trailing aircraft be separated by certain interval TI, as shown in the figure. It is also assumed that the speed of the lead aircraft does not vary much during the adjustment process. Governing equations can be represented as follows:

$$\frac{d\,(OGS)}{dt} = \frac{T - D}{M} \qquad (1)$$

$$S_L = \int TGS.\,dt \text{ and } S_o = \int OGS\,.\,dt \qquad (2)$$

$$\Delta S = S_L - S_o \qquad (3)$$

Where

- TGS and OGS are the ground speeds of lead aircraft and own aircraft
- T is the thrust and D is the drag on aircraft
- S_L and S_o are the distances travelled by lead and own aircraft in time t
- DS is the separation between the two aircraft

Assuming DS as the desired separation distance between the two aircraft, Separation Error (SE) is defined by EUROCAE [Ref.5] as

$$SE = \Delta S - DS \qquad (4)$$

Speed of own aircraft is to adjusted such that SE is reduced. EUROCAE approach proposes a performance parameter called Time Constraint (TC), by which time the separation is brought to desired level. Incremental speed (ΔVc) is computed as follows:

$$\Delta Vc = \frac{SE}{TC} \qquad (5)$$

DVc is considered as guidance parameter for adjustment of own aircraft speed. Since the own aircraft is expected to follow the speed profile of lead aircraft, the combined speed command can be represented as follows:

$$OGSc = TGS\,(t - TI) + \Delta Vc \qquad (6)$$

Resulting representation of guidance law is as shown in Fig.2. In order to preserve sign conventions with the basic formulation of EUROCAE, definition of variable SE is retained (and hence chosen as SE = -e) within the ΔVc shaping block.

A variation of this command was further suggested by the EUROCAE team in order to provide an additional anticipatory correction based on the variations in the speeds of lead aircraft [Ref.5,6].

Modified Form of ΔVc

The previous method generally results in high magnitudes of ΔV commands and also the time taken for aircraft to change the speed is not considered, which is not a practical situation. It is therefore proposed to employ an acceleration command as the guidance command which can be applied to Thrust Management Function (TMF) of Flight Management System (FMS) for controlling the speed of aircraft. The required acceleration comprises of two components; a_1 based on SE and a_2 based on difference between TGS and OGS.

Approach is to choose a1 such that SE becomes zero over the chosen time constraint TC. From fundamental principles it follows that

$$SE = \frac{1}{2}\,.\,a_1\,.\,TC^2 \quad \therefore\ a1 = 2.\,SE\,/\,TC^2 \qquad (7)$$

Approach to choose a_2 is such that the OGS reaches TGS in the chosen time interval TI in an ideal case of TGS being constant as follows:

$$a_2 = [TGS\,(t) - OGS\,(t)]\,/\,TI \qquad (8)$$

Under varying conditions of TGS and OGS, this is equivalent to derivative feedback of SE which improves tracking performance. In order to have flexibility over the a_2 feedback, a gain constant K is introduced resulting in total command as follows:

$$a = a_1 + K \cdot a_2 \tag{9}$$

Detailed parametric studies need to be carried out to optimize various design constants, which is beyond scope of the present conceptual study. For the current work, K is chosen such that the resulting acceleration commands are within reasonable limits during simulation studies. This formulation can be considered as guidance law for setting the thrust in order to ensure separation. Based on the mass of the aircraft and aerodynamic drag on the aircraft, the required thrust can be determined for the desired acceleration command as follows:

$$a = (T - D) / m \tag{10}$$

where T is the incremental thrust, D is the incremental drag, m is the mass and a is the desired acceleration.

Case Studies

Simulation studies have been conducted in both open and closed loop. For representing flight path of lead aircraft, actual flight histories of typical transport aircraft, which are recorded during flight and made available in public source [Ref.8] are used. The flight data is generally available for all phases starting from initial climb to final approach, roughly up to 1500 ft above airfield level. For the present studies, flight trajectory data starting from initial approach phase is extracted from the complete data. Flight trajectory parameters of one B747 aircraft flight, obtained using the method described above, is as shown in Fig.3.

For convenience, Along Track Distance (ATD) measured from the beginning of initial approach, say at around 12000 ft of height, as shown in the figure.

Open Loop Study

Objective of the case study is to analyze the separation when the own aircraft follows the flight path of lead aircraft after an interval of time, TI, with the same speed profile as that of lead aircraft as follows:

$$OGS\ (t) = TGS\ (t - TI) \tag{11}$$

Requirement for desired separation is chosen as 5 NM. In order to assess the separation as function of time interval, TI is chosen as 50 sec, 60 sec and 90 sec. Flight trajectory of one B747 aircraft, as shown in Fig.3 is chosen for lead aircraft. Time histories of spacing error, SE, are presented in Fig.4.

As can be seen from the figure, separation becomes critical as the time interval TI is reduced from 90 sec to 50 sec.

Closed Loop Simulation Using Speed Command

Speed Command, involving anticipatory term is considered for the guidance law for speed variation. Time responses of TGS, OGS, Spacing Error and the ΔVc are as shown in Fig.5. TI and TC are chosen as 60 sec and 30 sec respectively.

Closed Loop Simulation Using Acceleration Command

Constant TGS: In order to illustrate functioning of the concept, a simple case study for constant speed condition of lead aircraft is considered. Initial conditions are: TGS = 320 knots, OGS = 300 knots, Separation = 5.33 M. TI, TC and K are chosen as 60 sec, 30 sec and 3.5 respectively. Time responses of various flight parameters, obtained using guidance law for acceleration command are as shown in Fig.6.

Convergence of OGS and spacing error could be noticed from the results.

Varying TGS: Flight trajectory data of B747, as mentioned in Section - Open Loop Study is considered for the study. Time responses of various flight parameters, obtained using guidance law for acceleration command are as shown in Fig.7. TI and K are chosen as 60 sec and 3.0 respectively. As can be seen from the results, the spacing error gets reduced to less than 0.3 NM. The speed builds up gradually as against abrupt changes in the ΔV commands of the previous case.

The acceleration command varies in the range of ±1.3 m/sec2 which seem to be reasonable, being in the limits of ±0.15g [Ref.7]. Further optimizations are possible through detailed parametric studies involving different combinations of TI and TC.

Conclusions

Airborne Separation Assistance System is emerging as an important concept in the design of future ATM Systems in order to streamline the air traffic and to ensure less congested airspaces. While different types of separation are being studied, constant distance spacing is being considered from safety point of view. The analysis brings out that since ΔV command does not consider the time lags involved due to mass, drag and other dynamics of aircraft, engine and other systems and hence implementation would not be effective. Hence, a variant of guidance laws involving acceleration command has been proposed. This approach enables adjustment of thrust directly based on mass and drag leading to improved performance. Simulation studies have been carried out in open loop and closed loop for assessment of separation. For representing lead aircraft flight, actual flight data for approach phase the real flight available on flightaware.com for one B747 flight has been used. The simulation studies do not consider time lags of auto thrust management function and engine dynamics and effect of external winds. Detailed design studies, involving stability analysis and parametric studies are required to firm up the design constants.

Acknowledgements

The authors thank Dr.Shrikant Rao and Venkata Subbaiah of Honeywell Technology Solutions Lab, Bangalore and Dr. A. A Pashilkar, Senior Principal Scientist, CSIR-National Aerospace Laboratories (NAL), Bangalore for their critical review and constructive suggestions.

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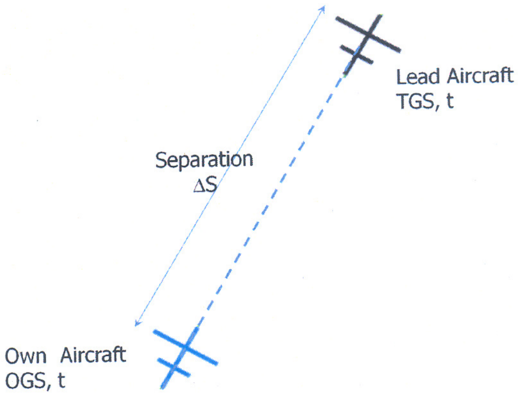

Fig.1 Relative Positioning Lead and Training Aircraft

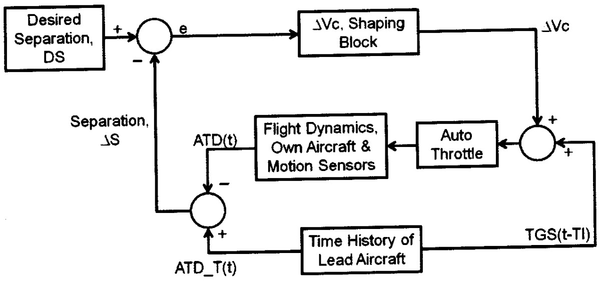

Fig.2 Schematic of Guidance Law Using ΔVc

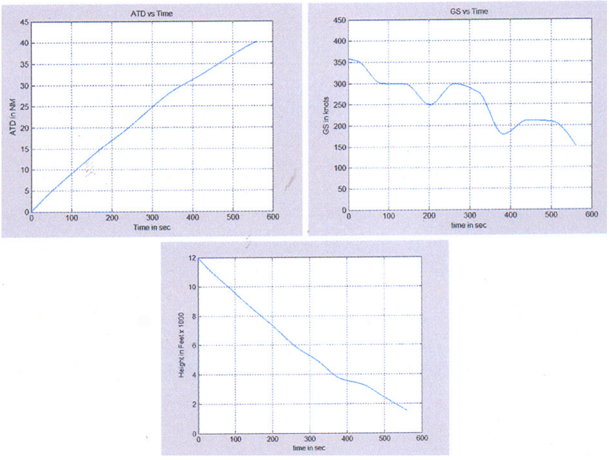

Fig.3 Flight Trajectory of One B747 During Approach for Landing

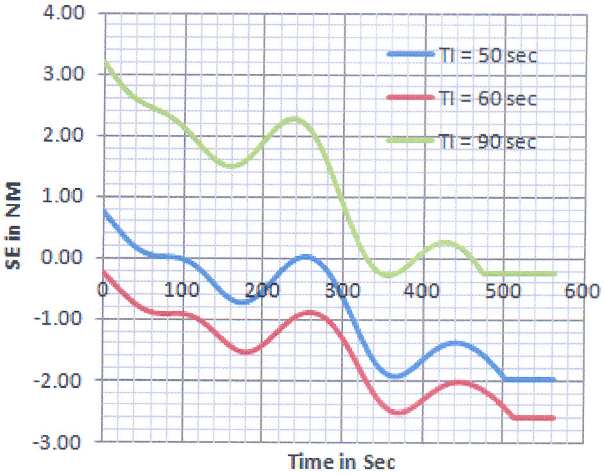

Fig.4 Spacing Error Obtained for B747

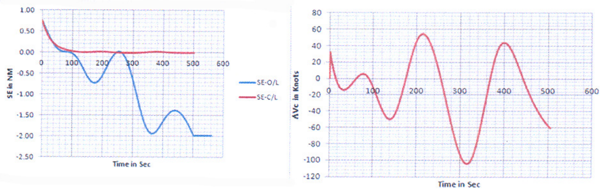

Fig.5 Time Responses for B747 Aircraft

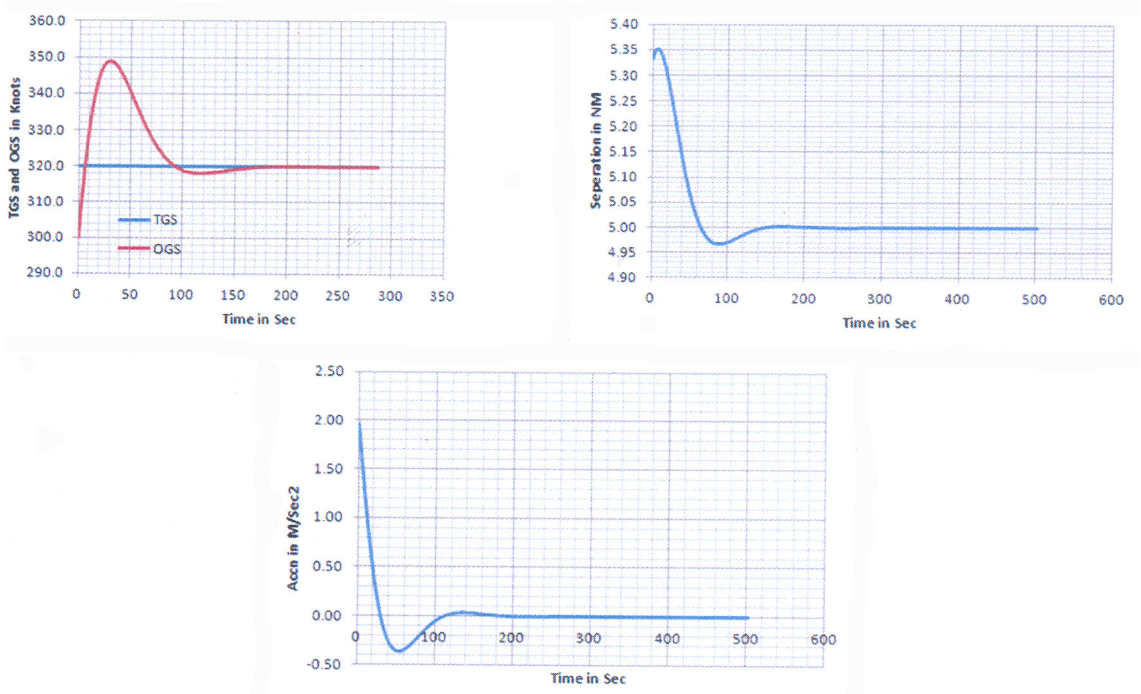

Fig.6 Time Response of Case Study with TGS = 320 Knots

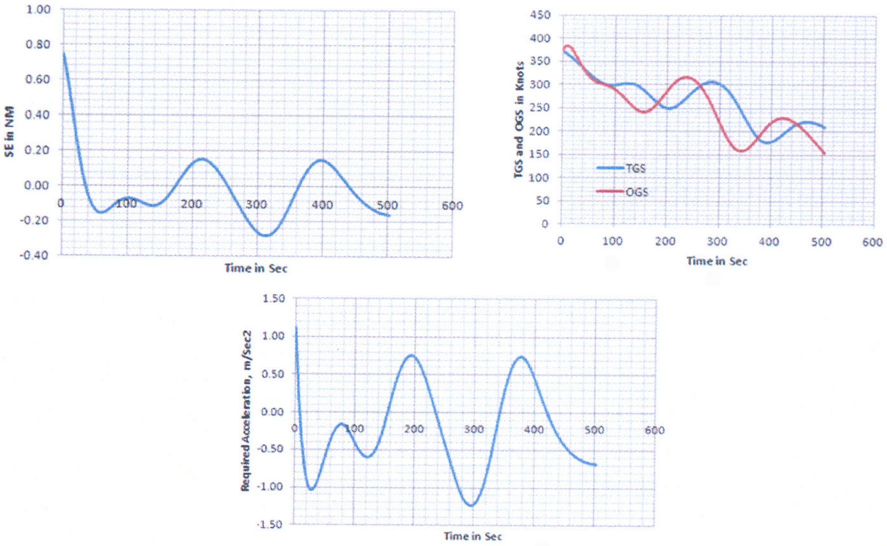

Fig.7 Time Responses for B747 Aircraft Using Acceleration Command