AIRCRAFT ARRIVAL MANAGEMENT SYSTEMS AND METHODS

BACKGROUND

Aircraft arrival trajectories are typically coordinated through a merge point before queuing up for landing on a runway. Air traffic controllers need to establish an arrival sequence with adequate separation between aircraft. To achieve such separation, controllers intuitively employ path stretching or speed control techniques. In some instances, a desired time delay is achieved by instructing an aircraft to turn onto an arc centered around a merge point for a specified distance before turning off the arc and toward the merge point. Currently, controllers lack precise tools for determining when to instruct an aircraft to turn toward the merge point so as to provide a safe and efficient landing sequence for a series of incoming aircraft. Controllers must err on the side of safety, which may result in excess spacing between aircraft, causing wasted time, fuel, and controller workload. Efficient systems and methods for providing altered flight paths to achieve optimal separation between successive pairs of incoming aircraft are therefore desirable.

SUMMARY

The present disclosure provides systems, apparatus, and methods relating to aircraft arrival management. In some examples, a method of controlling timing of aircraft landing may include selecting a first leading aircraft and a first trailing aircraft, each aircraft being on a flight path configured for landing on a runway. The method may include back calculating a trajectory profile from a touchdown point on the runway, to a current airspace position of the first leading aircraft, and estimating when the first leading aircraft will arrive at the touchdown point. The method may include back calculating a trajectory profile from the touchdown point to a current airspace position of the first trailing aircraft, and determining a time point when the first trailing aircraft will intersect an arc having a merge point. The method may include stopping back-calculation of the trajectory profile for the first leading aircraft at the time point when the first trailing aircraft will intersect the arc, determining a threshold separation point where a distance to the first leading aircraft is above a minimum radar separation threshold (R), and then calculating a delta distance that the first trailing aircraft should travel along the arc before turning toward the merge point to provide adequate separation between the first leading aircraft and the first trailing aircraft for safe landing. The delta distance (L) corresponds to a distance between the threshold separation point and the arc.

In some examples, a method of controlling timing of aircraft landing may include selecting a first leading aircraft and a first trailing aircraft, each aircraft being on a flight path configured for landing on a runway. The method may include back calculating flight trajectories for each aircraft from a touchdown point on the runway. The method may include determining a threshold separation distance required between the leading and trailing aircraft for safe landing, determining a threshold separation point where a distance to the first leading aircraft is above a minimum radar separation threshold (R), and then calculating a delta distance, based on the threshold separation distance, corresponding to a travel distance of the first trailing aircraft along an arc centered around a merge point, before turning toward the merge point. The delta distance (L) corresponds to a distance between the threshold separation point and the arc.

In some examples, a system for controlling timing of aircraft landing, may include one or more processors, a memory including one or more digital storage devices, and a plurality of instructions stored in the memory and executable by the one or more processors to back calculate flight trajectories for each of a leading aircraft and a trailing aircraft from a common touchdown point on a runway. The system may be configured to determine a threshold separation distance required between the leading and trailing aircraft for safe landing, and determine a threshold separation point where a distance to the first leading aircraft is above a minimum radar separation threshold (R). The system may then calculate a delta distance, based on the threshold separation distance, corresponding to a travel distance of the trailing aircraft along an arc centered around a merge point, before turning toward the merge point. The delta distance (L) corresponds to a distance between the threshold separation point and the arc.

Features, functions, and advantages may be achieved independently in various examples of the present disclosure, or may be combined in yet other examples, further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram of flight path envelopes for an aircraft arrival management system.

Fig. 2 is a schematic diagram of flight paths for a leading and a trailing aircraft in the flight path envelope of Fig. 1.

Fig. 3 is a schematic diagram of an aircraft arrival management system.

Fig. 4A is a schematic diagram of an altered flight path for the trailing aircraft generated by the aircraft arrival management system of Fig. 3.

Fig. 4B is a schematic diagram of a vertical profile of the altered flight path for the trailing aircraft shown in Fig. 4A.

Fig. 5A is a schematic diagram of flight descent paths for three consecutive aircraft showing unequal landing separation distances.

CLAIMS:

1. A method of controlling timing of aircraft landing, comprising:

selecting a first leading aircraft and a first trailing aircraft, each aircraft being on a flight path configured for landing on a runway,

back calculating a trajectory profile from a touchdown point on the runway, to a current airspace position of the first leading aircraft, and estimating when the first leading aircraft will arrive at the touchdown point,

back calculating a trajectory profile from the touchdown point to a current airspace position of the first trailing aircraft, and determining a time point when the first trailing aircraft will intersect an arc having a merge point center,

stopping back calculation of the trajectory profile for the first leading aircraft at the time point when the first trailing aircraft will intersect the arc,

determining a threshold separation point where a distance to the first leading aircraft is above a minimum radar separation threshold (R), and

calculating a delta distance (L) that the first trailing aircraft should travel along the arc before turning toward the merge point to provide adequate separation between the first leading aircraft and the first trailing aircraft for safe landing, wherein the delta distance (L) corresponds to a distance between the threshold separation point and the arc.

2. The method of claim 1, further comprising:

redesignating the first trailing aircraft as a second leading aircraft, and selecting a second trailing aircraft,

back calculating trajectories of the second leading aircraft and the second trailing aircraft from the touchdown point, and

calculating a delta distance (L) corresponding to a travel distance (L) of the second trailing aircraft along the arc before turning toward the merge point to provide adequate separation between the second leading aircraft and the second trailing aircraft for safe landing.

3. The method of claim 2, further comprising:

determining if the first trailing aircraft is faster than the first leading aircraft, and if so, adding an extension distance (E) to the delta distance (L) corresponding to a travel distance (L+E) of the first trailing aircraft along the arc before turning toward the merge point.

4. The method of claim 3, wherein the extension distance (E) is calculated by:

calculating a time to touchdown for the first leading aircraft, and

adding the time to touchdown for the first leading aircraft to a flight time of the first trailing aircraft along the arc before turning toward the merge point.

5. The method of claim 1, wherein the delta distance (L) is zero when the separation point is inside the arc.

6. The method of any one of claims 1-5, further comprising:

using aircraft performance data in the back calculation steps.

7. The method of any one of claims 1-6, further comprising:

for each of the first leading aircraft and the first trailing aircraft, using aerodynamic coefficients of the aircraft in a three degree of freedom kinematic modeling of the aircraft's dynamic motion.

8. The method of any one of claims 1-7, further comprising:

using weather data in the back calculation steps.

9. The method of any one of claims 1-8, further comprising:

adjusting back calculations based on changing wind conditions.

10. The method of any one of claims 1-9, further comprising:

assigning the first trailing aircraft to one of multiple arcs having a common center at the merge point.

11. A method of controlling timing of aircraft landing, comprising:

selecting a first leading aircraft and a first trailing aircraft, each aircraft being on a flight path configured for landing on a runway,

back calculating flight trajectories for each aircraft from a touchdown point on the runway,

determining a threshold separation distance (D) required between the leading aircraft and trailing aircraft for safe landing,

determining a threshold separation point where a distance to the first leading aircraft is above a minimum radar separation threshold (R), and

calculating a delta distance (L), based on the threshold separation distance (D), corresponding to a travel distance (L) of the first trailing aircraft along an arc centered around a merge point, before turning toward the merge point, wherein the delta distance (L) corresponds to a distance between the threshold separation point and the arc.

12. The method of claim 11, wherein the threshold separation distance (D) is a distance from the leading aircraft to the separation threshold point beyond the arc.

13. The method of claim 12, wherein the delta distance is zero when the separation threshold point is inside the arc.

14. The method of any one of claims 11-13, further comprising:

redesignating the first trailing aircraft as a second leading aircraft, and selecting a second trailing aircraft,

back calculating trajectories of the second leading aircraft and the second trailing aircraft from the touchdown point, and

calculating a delta distance (L) corresponding to a travel distance (L) of the second trailing aircraft along the arc before turning toward the merge point to provide adequate separation between the second leading aircraft and the second trailing aircraft.

15. A system for controlling timing of aircraft landing, comprising:

one or more processors,

a memory including one or more digital storage devices, and

a plurality of instructions stored in the memory and executable by the one or more processors to:

back calculate flight trajectories for each of a leading aircraft and a trailing aircraft from a common touchdown point on a runway,

determine a threshold separation distance (D) required between the leading aircraft and trailing aircraft for safe landing,

determine a threshold separation point where a distance to the first leading aircraft is above a minimum radar separation threshold (R), and

calculate a delta distance (L), based on the threshold separation distance (D), corresponding to a travel distance (L) of the trailing aircraft along an arc centered around a merge point, before turning toward the merge point, wherein the delta distance (L) corresponds to a distance between the threshold separation point and the arc.

16. The system of claim 15, wherein the threshold separation distance (D) is a distance from the leading aircraft to the separation threshold point beyond the arc.

17. The system of claim 15 or 16, wherein the plurality of instructions are further executable by the one or more processors to:

determine if the trailing aircraft is faster than the leading aircraft, and if so, add an extension distance (E) to the delta distance (L) corresponding to a travel distance (L+E) of the trailing aircraft along the arc before turning toward the merge point.