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Airborne Precision Spacing (APS) Dependent Parallel Arrivals (DPA)

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Abstract

The Airborne Precision Spacing (APS) team at the NASA Langley Research Center (LaRC) has been developing a concept of operations to extend the current APS concept to support dependent approaches to parallel or converging runways along with the required pilot and controller procedures and pilot interfaces. A staggered operations capability for the Airborne Spacing for Terminal Arrival Routes (ASTAR) tool was developed and designated as ASTAR10. ASTAR10 has reached a sufficient level of maturity to be validated and tested through a fast-time simulation. The purpose of the experiment was to identify and resolve any remaining issues in the ASTAR10 algorithm, as well as put the concept of operations through a practical test.

The experiment was designed to progress through three comparisons, building up a validation of ASTAR10 and then testing ASTAR10 for performance. First ASTAR9 and ASTAR10 were given identical one-runway scenarios, and the results were compared for consistency. Second, ASTAR10 was given a two-target scenario and a one-runway scenario designed to produce the same spacing. ASTAR10's performance was then tested under various criteria, including wind forecast error, different runway separations, and both one-target-two-runway and two-target-two-runway scenarios.

The work resulted in significant insights to be integrated into the NASA Langley Air Traffic Operations Lab (ATOL) and Cockpit Motion Facility (CMF) simulators for use in future APS studies and will aid in the preparations for subsequent human-in-the-loop (HITL) studies. ASTAR10 was validated and the significance of a secondary target was established. Both the APS Dependent Arrivals concept of operations and the ASTAR10 algorithm were refined.

1. Introduction

a. Introduction

Improved arrival efficiency, in terms of both capacity and environmental impact, is an important part of improving National Airspace System (NAS) operations. The Airborne Precision Spacing (APS) team at the NASA Langley Research Center (LaRC) has been developing a concept of operations to extend the current APS concept to support dependent arrivals to parallel approaches along with new pilot and controller procedures and pilot interfaces [1]. This is intended to allow aircraft managing their own spacing to land on parallel runways, achieving improved arrival precision and airport capacity while also allowing aircraft to utilize Optimized Profile Descents (OPD) to improve fuel efficiency. This would result in greater aircraft throughput at the runways, less fuel consumption and noise on approaches, and Air Traffic Control (ATC) traffic planning at a more strategic level [2-4]. This system could be utilized at existing airports as well as considered in the design of future airports.

To achieve successful development and field-testing of integrated air/ground arrival operations procedures, the technology readiness level, or maturity, of the airborne spacing tool needed to be increased. Tools, procedures, and interfaces to allow airborne spacing based on two targets were developed to expand current airborne spacing operations to support dependent, parallel approach operations (also called staggered operations). A staggered operations capability for the Airborne Spacing for Terminal Arrival Routes (ASTAR) tool was developed and designated as ASTAR10. The tool allows spacing relative to two target aircraft including one that lands on a different runway. The ASTAR-equipped aircraft is instructed to achieve the assigned spacing behind two aircraft, one landing on the same runway, resulting in in-trail spacing, and the other landing on a parallel runway, resulting in stagger spacing. The required stagger distance is dependent on the distance between runway centerlines. A runway separation of 2500 ft to 4000 ft requires a 1.5 nmi stagger distance, while a separation 4000 ft to 9000 requires a 2.0 nmi stagger distance.

ASTAR10 has reached a sufficient level of maturity to be validated and tested. A simulation experiment of the new precision spacing concept was performed to allow for refinements to the concept of operations as well as provide a first look at possible benefits and system performance improvements of these new operations. The work resulted in significant insights to be integrated into the NASA Langley Air Traffic Operations Lab (ATOL) and Cockpit Motion Facility (CMF) simulators for use in future APS/ASDO studies and will aid in the preparation for subsequent human-in-the-loop (HITL) studies. This experiment consisted of analyses of fundamental performance and operations. It did not include any HITL elements or advanced performance elements.

b. Operations Terminology

In this paper, four criteria are used to distinguish the particular operations. These criteria are: the number of runways in use, whether the spacing aircraft is tracking one target or two, whether the target aircraft is approaching the same runway or a parallel runway as the spacing aircraft, and whether the target aircraft's spacing criteria are the dominant criteria.

The number of runways represents a high-level variable. One-runway operations mean that only one runway is in use, thus all aircraft land on that runway, in-trail behind one another, with only one possible target. If more than one parallel runway is in use, the operation is a parallel approach operation. This is illustrated below in Figure 1.

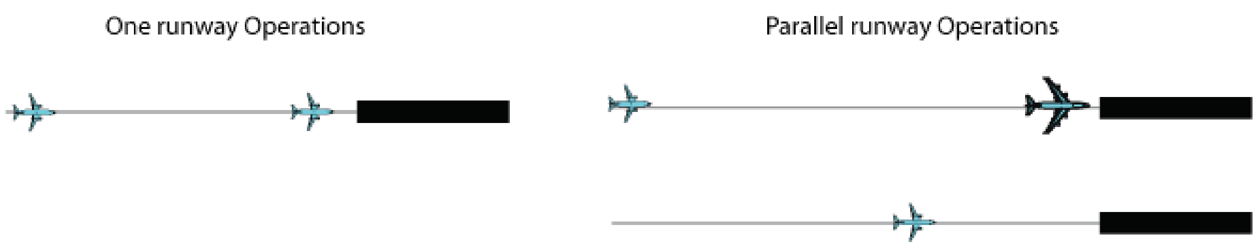

Figure 1: One-Runway operations vs. Parallel-Runway operations.

In parallel operations, aircraft can space off of an aircraft approaching the same runway, an aircraft approaching a parallel runway, or both aircraft simultaneously. If the spacing aircraft is only spacing off of one aircraft, it is called a one-target operation. If the spacing aircraft is spacing off of aircraft approaching both runways, it is called a two-target operation. Note that in one-target operations, the spacing aircraft may space off of only the aircraft approaching a parallel runway, while ignoring an aircraft approaching the same runway, or vice versa. Also note that the number of targets only refers to how many aircraft are being used for spacing operations, not how many aircraft are present. Thus, one-target operations may be in use when there are multiple aircraft that could be targeted. This is illustrated below in Figure 2.

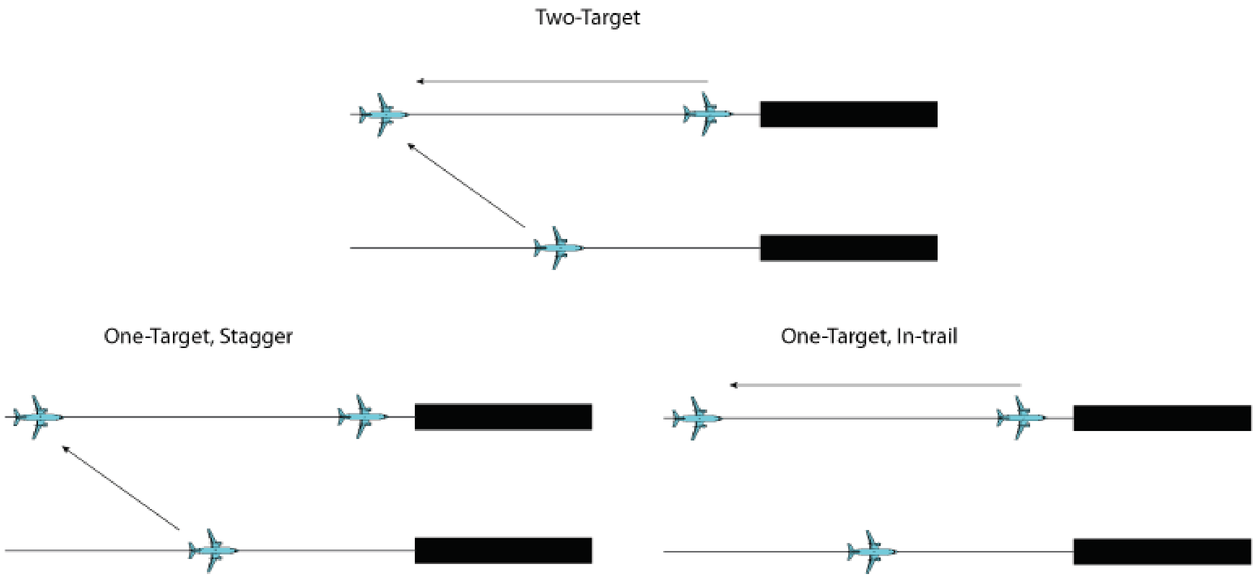

Figure 2: One-Target vs. Two-Target operations.

If a target aircraft is approaching the same runway as the spacing aircraft, the spacing is said to be in-trail spacing. If the target aircraft is approaching a parallel runway, the spacing is said to be stagger spacing. Two-target operations necessarily use both in-trail and stagger spacing, while one-target operations may use either one. This is illustrated above in the one-target diagrams of Figure 2.

Finally, in two-target operations, a distinction is made between a primary target and a secondary target. When determining this, the spacing aircraft calculates a resultant spacing position for each spacing aircraft. The aircraft whose spacing interval results in a spacing position further back is defined as the primary target, while the secondary target's spacing interval results in a closer spacing position. The spacing aircraft precisely meets the spacing interval of the primary aircraft, while exceeding or meeting the spacing interval of the secondary aircraft. This is illustrated below in Figure 4.

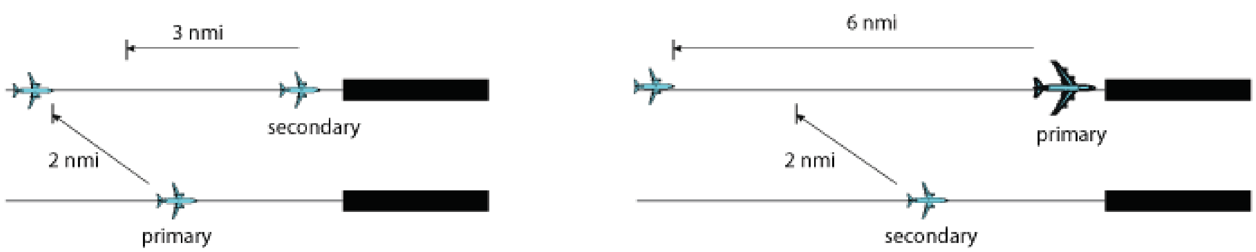

Figure 3: Primary vs. Secondary targets.

2. Objectives

The purpose of the experiment was primarily to identify and resolve any remaining issues in the ASTAR10 algorithm, as well as put the concept of operations through a practical test. This was done during the development of the experiment scenarios. The experiment itself was divided into two segments. The first segment was used to validate ASTAR10 against ASTAR9, the previous iteration of the algorithm, while the second segment was used to address several research questions.

a. Research Questions

During the development of the concept of operations several research questions were identified which could be answered by one or more system performance studies. This experiment was designed to address two of these:

- What is the impact of two-target operations versus one-target operations in a parallel approach environment?
  - Hypothesis: Two-target operations will yield fewer separation violations against the secondary aircraft, since spacing is being managed against both targets.
- How stable are one- and two-target stagger operations?
  - Hypothesis: Both operations will be equally stable.

3. Methodology

a. Airspace Environment

Portions of the Dallas-Ft. Worth International Airport (KDFW) airspace environment were simulated in the experiment. To meet the objectives of this experiment, two pairs of runways were needed: one pair separated by 2500 ft to 4300 ft and the other pair separated by 4300 ft to 9000 ft. No two pairs of KDFW runways satisfied these criteria so a new "virtual" runway was added. Runway 18V was placed between existing runways 18R and 17R. Approaches to runways 18R and 18V are separated by 2500 ft while runways 18V and 17R are separated by 5100 ft. OPDs were designed that ended at the appropriate ILS for each runway. A chart of the 18R/18V/17R arrival paths is shown in Figure 5. The southwest arrival path is split into two separate routes farther out (at approximately 153 nmi out from the runway). Note that the final approach leg for approaches from the west was extended to avoid head-on base legs and introduce the possibility of an aircraft intercepting its final approach leg prior to that its stagger target aircraft doing so.

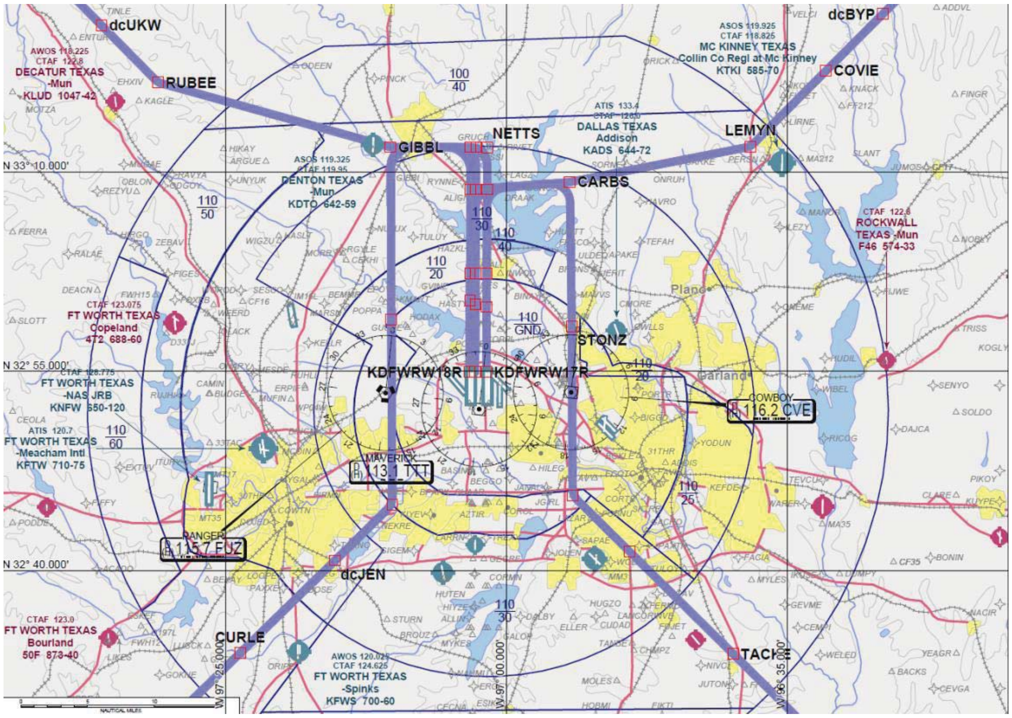

Figure 4: Approach chart for KDFW.

b. Traffic Scenario

The traffic scenarios for this batch study consisted of 50 aircraft to each of the selected parallel runways (e.g., KDFW 18R and 18V or 18V and 17R). Initialization of the aircraft was at cruise altitudes and speeds approximately 60 nmi prior to Top-of-Descent. Aircraft spacing within or between streams consisted of a mix of in-trail and staggered aircraft depending on the scenario objectives. Several sets of initial parameters (aircraft type, weight, altitude, and speed; route distribution) were used across test conditions to enable aircraft-to-aircraft performance comparisons between the test conditions, while also providing multiple variations.

c. Aircraft Distribution

The aircraft type and route distributions were generated from statistics derived from a single day of operations at DFW. The aircraft types observed were then pruned to aircraft types available for simulation in TMX. The results are shown in Table 1 below.

Table 1: Aircraft Distribution

BADA Model*	Aircraft Types	Ref. Mass Mkg	Ref. Weight Klb	V_{stall}-Landing	Number Observed	Observed %	Percent Used
CRJ1	Canadair Regional Jet	21.0	46.2	108	76	7.8	10
A319	A319	60.0	132.0	94	66	6.8	10
B737	B737-700	60.0	132.0	103	87	8.9	15
MD83	MD-83	61.2	134.6	112	633	64.9	25
B753	B757	101.6	223.5	109	71	7.3	15
B763	B767-300	150.0	330.0	113	16	1.6	10
B773	B777	237.6	522.7	111	24	2.5	10
B744	B747-700	285.7	628.5	118	2	0.2	5

*The BADA Model number represents the identification of the aircraft model in the simulation software

The observed statistics significantly over-represented MD83 aircraft and the northeast quadrant. As the purpose of the experiment was not to model an actual DFW traffic environment, these statistics were modified to represent a more general distribution. The aircraft type distribution can be seen above in the Percent Used column, while the quadrant distribution was split 50/50 by east/west and 60/40 by north/south, resulting in an aircraft distribution of 30/30/20/10/10 for the northeast, northwest, southeast, and two southwest routes.

d. Wind

One of the wind conditions described in Ref [5] was used in this experiment. The wind scenario chosen was the data set for March 6, 2009. It was selected as having reasonable characteristics in strength, direction, and variation.

Charts of the selected data set were inspected to determine ten altitudes that would produce representative interpolations of the four tabulated parameters, true wind speed and direction, and forecast wind speed and direction. The truth wind was used to determine actual aircraft performance, while the forecast wind was used for scheduling and aircraft trajectory predictions. Ten data points were used to describe the truth and forecast winds in the TMX software. The results of this process are depicted in Figure 6.

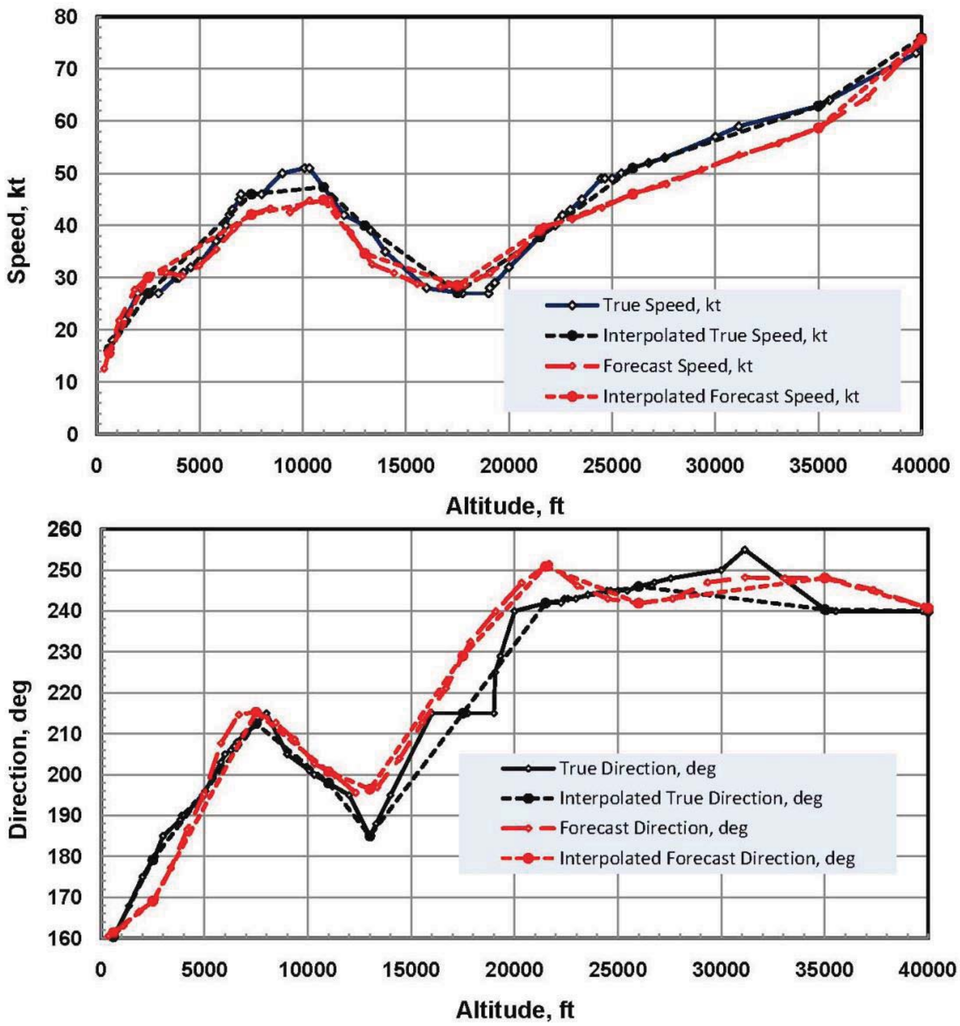

Figure 5: Truth and Forecast wind from the 06MAR09 dataset with altitudes selected for this experiment.

The characteristics shown in the chart are wind speeds of 60-70 kt at cruise altitudes, 30-40 kt between 20,000 and 10,000 ft, 40-50 kt between 10,000 and 5000 ft, and 15 kt at the airport surface. The wind direction is WNW at cruise altitudes, S between 20,000 and 13,000 ft, SW between 13,000 and 8000 ft, and SSE at the surface. Aircraft on approach encountered slight crosswinds from the right veering to 20 degrees from the left at the runway threshold.

The wind models for this study were then generated using the interpolated speed and direction values for the ten selected altitudes. The wind fields were laterally homogeneous throughout the region of the simulation.

e. Independent Variables

The independent variables for this experiment were wind (varying from no wind, to wind with accurate forecast, to wind with a forecast error), runway separation (2500 ft or 5100 ft), and number of target aircraft (one- or two-target operations). The final experiment matrix is provided below in Table 2:

Table 2: Final Experimental Matrix

Scenario	Active Runways	Wind/Forecast Error	Spacing/Operations
1	18R	None/No	In-Trail One-Target
2	18R	None/No	In-Trail One-Target modified spacing goal (see text)
4	18R/18V	None/No	Two-Target
5	18V/17R	None/No	Two-Target
6	18R/18V	Nominal/No	Two-Target
7	18V/17R	Nominal/No	Two-Target
8	18R/18V	Nominal/Yes	Two-Target
9	18V/17R	Nominal/Yes	Two-Target
10	18R/18V	None/No	One-Target
11	18V/17R	None/No	One-Target
12	18R/18V	Nominal/No	One-Target
13	18V/17R	Nominal/No	One-Target
14	18R/18V	Nominal/Yes	One-Target
15	18V/17R	Nominal/Yes	One-Target

Scenario 1 was run with both ASTAR9 and ASTAR10 software, thereby providing a validation test for ASTAR10's one-runway operations. Scenarios 2 and 4 were designed to produce the same spacing between sequential aircraft, but with one-runway operations for scenario 2 and two-runway, two-target operations for scenario 4, thereby providing a validation test for ASTAR10's two-target operations. From there on, scenarios 4 through 9 and scenarios 10 through 15 were designed as mirror sets, with scenarios 4 through 9 using two-target operations while scenarios 10 through 15 used one-target operations. Within each operations grouping of scenarios, the scenarios were also divided between wind conditions. Thus, scenarios 4, 5, 10, and 11 experienced no wind, scenarios 6, 7, 12, and 13 experienced wind with an accurate forecast, and scenarios 8, 9, 14, and 15 experienced wind with a forecast error. Scenarios also alternated between runway configurations, so that all even-numbered scenarios landed on runways 18R and 18V, while all odd-numbered scenarios landed on runways 18V and 17R. For the purposes of comparing operations differences, this allows a direct 1-to-1 comparison of scenarios 4 and 10, 5 and 11, 6 and 12, 7 and 13, 8 and 14, and 9 and 15, while also isolating wind conditions and runway differences. The statistical analyses compared the scenarios accordingly.

f. Dependent Variables

The dependent variables tracked for data analysis, taken from the simulation software, were the closest direct-line distance between the spacing aircraft and the traffic-to-follow (TTF2ClosestCG), the arrival error (CrossingTimeError), the total number of speed changes (SpdChanges(total)), and the actual time of arrival (ATA). The closest distance was used to identify separation violations with respect to the second target when comparing scenarios 4 through 9 to scenarios 10 through 15. If the closest point was below the minimum separation requirements, a violation would have occurred. Arrival error was used as a performance metric when comparing scenarios 4 through 9 to scenarios 10 through 15. The ideal arrival error was zero, with either a positive or a negative error indicating less than perfect performance. The speed changes generated by the ASTAR10 algorithm to meet the spacing goal were not separated from the speed changes required by the arrival procedure. Arrival time was used to calculate achieved stagger spacing in Scenario 4 and achieved in-trail spacing in Scenario 2. To do this, the arrival time of one aircraft was compared to that of the following aircraft. The difference between them was the in-trail spacing for scenario 2 and the stagger spacing for scenario 4. The scenarios were designed so that Scenario 4's stagger spacing should have been comparable to Scenario 2's in-trail spacing. Arrival error could not be used because of the nature of the spacings being compared. Arrival time was used solely for validation purposes. Closest distance was used to answer the first research question. Arrival error and the number of speed changes were used to answer the second research question.

g. Spacing Commands

Spacing commands were given to the aircraft depending on their in-trail or stagger requirements. The required in-trail wake-vortex separations were 2.5 nmi, 4 nmi, and 5 nmi, depending on the interaction of leading and following aircraft weight class. These requirements were given a 0.5 nmi buffer and then converted into times using an assumed final approach speed (FAS) of 139 knots and incorporating the forecast wind. The stagger spacing requirements were 1.5 nmi for 18R/18V and 2.0 nmi for 18V/17R. These requirements were given a 0.2 nmi buffer, and the 18R/18V requirement was expanded to 2.1 nmi to ensure 3 mile separation prior to final approach (required to maintain radar separation prior to final approach, see section 7.a). The stagger requirements were given as distances.

h. Aircraft Assignments

Two sequences of 100 random numbers were generated and assigned to a sequential numbering scheme (in its original, random order) using Microsoft Excel Spreadsheet's Rand() command. The results were then separately re-ordered according to the sequences of random numbers, resulting in two random sequences of a sequential numbering scheme. Aircraft and routes were sequentially assigned to the separate sequences of random numbers according to their statistical distribution (20% = 20 AC). The tables were then re-sorted according to the sequential numbering scheme, resulting in a single numbering scheme ordering from 1 to 100 and a random association of aircraft and routes.

Aircraft were taken from the random table and assigned to runways in order, according to direction of origin (routes from the east were assigned to the eastern runway, etc). This resulted in two sequences of random aircraft, one to each runway. The runway assignments were then blended together in a stagger pattern, with aircraft being assigned to alternating runways, and in-trail spacing time was derived from the resulting table. Each aircraft then had a separate Estimated Time of Arrival (ETA) calculated from its in-trail spacing and stagger spacing time separations. The larger of the two values becomes the primary spacing command. The aircraft this command related to was called the primary aircraft, while the other aircraft being spaced against was called the secondary aircraft. In this simulation, secondary aircraft were assigned a 'no closer than' spacing command, meaning that positive errors (representing being farther away than the spacing command required) were ignored. The ETA for next aircraft was then calculated based on those for previous aircraft and specified spacing times. The time-differences between the aircraft were then calculated. This sequence of aircraft, routes, and ETA differences was then entered into the existing Scenario Generator to generate a TMX input file with ASTAR9 (in-trail only) spacing commands. This file was then manually edited to include the appropriate ASTAR10 stagger and secondary-target spacing commands. Below, Figure 7 details an example random schedule generation of four aircraft, while Figure 8 shows how the scheduled spacing and primary/secondary relationships were determined.

As an example:

One could take the random numbers

0.0357	1.2583
1.2576	0.2485
0.5137	4.2153
8.2145	2.9543

Assign a sequential order of 1-4 to each

0.0357	1	1.2583	1
1.2576	2	0.2485	2
0.5137	3	4.2153	3
8.2145	4	2.9543	4

Re-order the sequences according to the random numbers

0.0357	1	0.2485	2
0.5137	3	1.2583	1
1.2576	2	2.9543	4
8.2145	4	4.2153	3

Assign aircraft types to one set and routes to another, in order according to their proportions

0.0357	1	MD83	0.2485	2	AEX
0.5137	3	B757	1.2583	1	BGD
1.2576	2	B757	2.9543	4	BGD
8.2145	4	A319	4.2153	3	FSM

Re-order according to the sequential number scheme

0.0357	1	MD83	1.2583	1	BGD
1.2576	2	B757	0.2485	2	AEX
0.5137	3	B757	4.2153	3	FSM
8.2145	4	A319	2.9543	4	BGD

Assign aircraft types to the corresponding routes

MD83	BGD
B757	AEX
B757	FSM
A319	BGD

Separate them according to their approaches. Since AEX and FSM approach from the same direction, while BGD approaches from the other direction, the results should look like

B757	BGD	B757	AEX
A319	BGD	MD83	FSM

Finally, order them in a staggered pattern

B757	BGD
B757	AEX
A319	BGD
MD83	FSM

Figure 6: Aircraft type and runway assignment example.

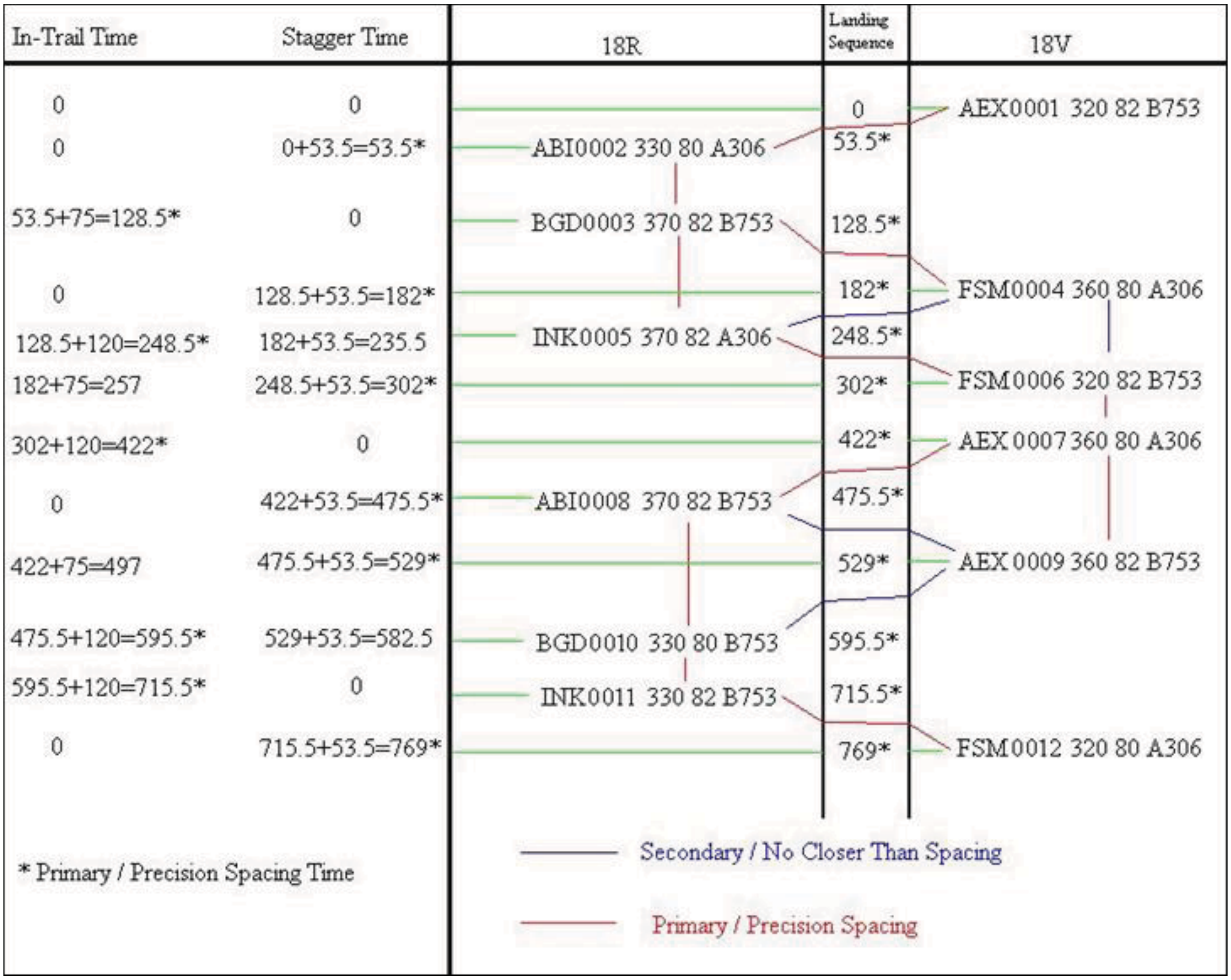

Figure 7: Aircraft scheduling example.

i. Simulation Facility

Traffic Manager (TMX) software, the simulation environment for the experiment, is a multiple aircraft simulation environment developed by the National Aerospace Laboratory (NLR) of the Netherlands. It was originally designed in 1996 to study airborne separation assurance with multiple aircraft interactions in a Free Flight environment. It has been continually developed since that time by both the NLR and NASA Langley for use in a wide range or simulation projects [6]. It is capable of generating, simulating, and managing multiple aircraft simultaneously in an airspace simulation. The ASTAR development team has integrated the ASTAR10 algorithm into TMX, allowing the aircraft to fly using ASTAR10 procedures. The version of TMX used was v9.3.07. It was implemented on a single desktop computer.

j. Runs

Each scenario was run under two different randomly generated traffic conditions, as described previously. Each of these conditions was then run twice, employing performance randomization factors built into TMX, including pilot model reaction times, atmospheric and sensor noise, and randomized sampling time. This provided a total of 4 iterations of each scenario.

4. Validation

a. Purpose

The ASTAR10 algorithm represents a new modeling software package, with substantial changes from the previous iteration. It is thus important to validate its performance against the previous algorithm to ensure it maintains sufficiently accurate performance.

b. Findings

In comparing the performance of ASTAR10 to ASTAR9, the differences between arrival spacing was compared, using ATAs. ASTAR9 presented a sample size of 198 values (99 for each of two traffic scenarios), while ASTAR10 presented 396 (99 for each of two traffic scenarios; each scenario run twice). Because of this discrepancy, the ASTAR10 data was averaged between the runs of each traffic scenario, resulting in 198 values. It was expected that there would be no difference in the spacing performance between ASTAR9 and ASTAR10. An F-test was performed to test this hypothesis. The F-value was 0.10 and the p-value was 0.75. From this, the null hypothesis that there is no statistically significant difference between the two data sets was supported.

In comparing the performance of ASTAR10's one-target operations (scenario 2) to its two-target operations (scenario 4), a sample size of 396 values for each scenario was obtained. The F-value was 0.04 and the p-value was 0.83. From this, the null hypothesis that there is no statistically significant difference between the two data sets was supported. The results are shown below in Figure 9.

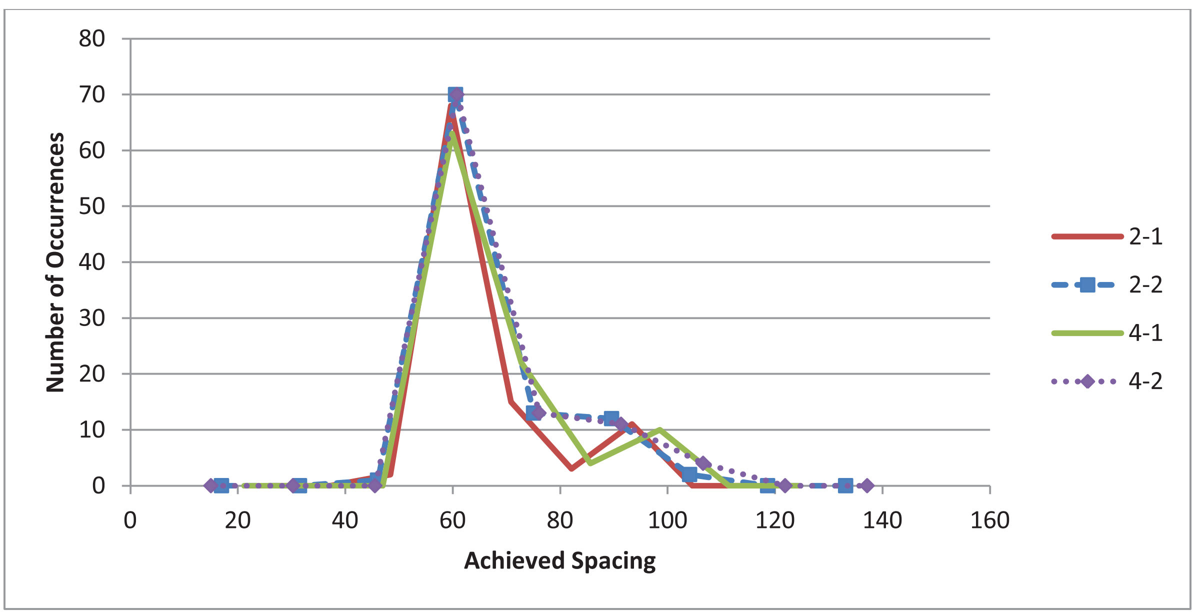

Figure 8: Distributions of differences in ATA.

5. The Impact of Two-Target Operations

a. Purpose

The first research question asked what the impact of two-target operations vs. one-target operations is. This question was asked in order to assess the importance of a secondary target. It had been considered that the aircraft may be able to maintain separation with both targets simply by monitoring their primary target aircraft, and that any secondary aircraft would necessarily stay a greater distance away. This was uncertain in ASTAR10, however, because the algorithm does not maintain current spacing, but rather predicted spacing at the runway. It is thus possible for current spacing to be either greater than or less than the desired spacing at the runway. The amount of difference between current spacing and final spacing is monitored, allowable error is reduced as an aircraft gets closer to the runway, and a spacing buffer is included to ensure that minimum separation standards are not violated. However, a secondary aircraft's error with its own primary could place it out of position, and thus too close to another trailing aircraft.

b. Findings

In addressing the first research question TTF2ClosestCG values were compared to the required separation criteria. Each scenario had a sample size of 100. No statistically significant variation was observed; however, a noticeable, if minor, difference was observed. While the two-target operations saw no separation violation against the secondary aircraft, the one-target operations saw a total of 4 such violations, out of a total of 2328 aircraft. Given the nature of these events, this difference is considered significant, if infrequent. Operationally speaking, one separation violation per 582 aircraft is unacceptable. These violations are occurring specifically because the spacing between an aircraft and its secondary target is not being monitored. Since the purpose of identifying a second target is to avoid separation violations with it, the hypothesis that two-target operations will see fewer separation violations against the secondary aircraft was supported. The results are below in Table 3.

Table 3: Separation Violations

Separation Violations	1-1	2-1	1-2	2-2
Scenario 4	0	0	0	0
Scenario 5	0	0	0	0
Scenario 6	0	0	0	0
Scenario 7	0	0	0	0
Scenario 8	0	0	0	0
Scenario 9	0	0	0	0
Scenario 10	0	0	0	0
Scenario 11	0	0	0	0
Scenario 12	0	0	0	0
Scenario 13	0	1	0	1
Scenario 14	0	0	0	0
Scenario 15	0	1	0	1

6. Stability of Operations

a. Purpose

The second research question asked how stable one- and two-target operations are. Because two-target operations represent a new capability, it was important to establish the stability of the aircraft arrival streams. This fact was emphasized early in the experiment development as many arrival streams resulted in periodic excessive spacing. The problem was identified as resulting from a transition from time-based stagger spacing to distance-based stagger spacing for final approach. The time-based spacing commands had been based on an average final landing speed, which was used to convert from the distance requirements to the time-based spacing command. The distance-based commands for final approach, however, allowed the ASTAR algorithm to use each aircraft's individual speed in performing calculations, thus resulting in a different spacing. Specifically, aircraft typically attempted to gain about 2 seconds. Each individual aircraft was able to do this for its own spacing, but all aircraft after them would then have to advance the same amount. Because of this, each aircraft would not only need to gain its own 2 seconds, but also 2 more seconds for each aircraft ahead of it in the arrival stream. This sum continued to build until one aircraft was incapable of making up the time, resulting in a single, large spacing error and then restarting the process. This issue was resolved by changing the stagger spacing commands to distance-based spacing throughout the entire route.

b. Findings

In addressing the second research question, two variables were considered. Each scenario produced a total of 100 samplings in the first variable, which was the number of recorded speed changes. The results of the chi-square tests showed a statistically significant difference between scenarios 5 and 11, 6 and 12, and 7 and 13. The differences, however, were varied, showing preference for different conditions in different scenarios. The results are below in Table 4:

Table 4: Number of commanded speed changes.

Speed Changes	1-target	2-target
4 vs. 10	2981	2840
5 vs. 11	3181	3348
6 vs. 12	5113	4697
7 vs. 13	3408	4534
8 vs. 14	5841	5888
9 vs. 15	5104	4978

Each scenario produced a total of 100 samplings in the second variable, which was the arrival error. The results of the single-factor ANOVA, as performed for each set of scenarios, showed no statistically significant difference. Additionally, an F-Test was performed for each set of scenarios, which indicated a minor but statistically significant difference under ideal conditions as well as under wind error conditions. The results of both tests are below in Table 5 and Figure 10:

Table 5: CrossingTimeError ANOVA & F-Test

Scenarios	ANOVA F-Value	ANOVA P-Value	F-Test F-Value	F-Test P-Value
4 vs. 10	0.122243	0.726707	0.871045	0.084183
5 vs. 11	0.039274	0.842957	0.787677	0.008671
6 vs. 12	0.167455	0.682494	0.926049	0.221617
7 vs. 13	2.363388	0.124609	1.053499	0.301475
8 vs. 14	0.179685	0.671758	0.818369	0.022805
9 vs. 15	0.173960	0.676729	1.368358	0.000893

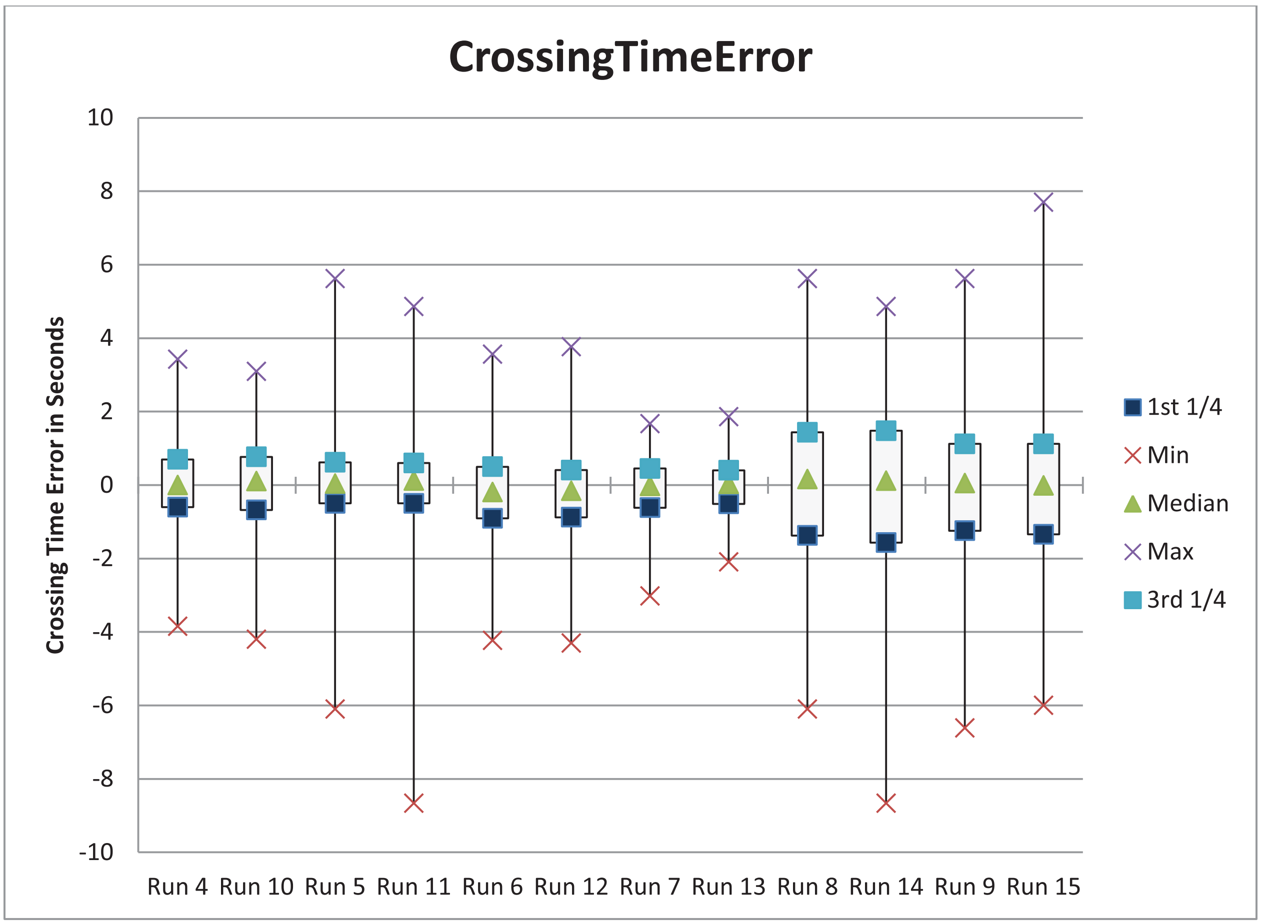

Figure 9: CrossingTimeError.

The lack of difference under wind conditions without error as well as the lack of any such significance in the ANOVA indicate that this may be the result of a Type I error, or false positive, in the F-Test.

Because the differences in the number of speed changes commanded were inconsistent, the addition of a second target does not appear to change the stability of the operations at all.

7. Other Findings

a. Separation Prior to Stagger Operations

During the development of this experiment, difficulties with maintaining separation during the stagger operations were found. The goal of the stagger operations was to achieve as high runway throughput as possible while each aircraft performed an OPD. However, it was found that, with the closer spaced runways that only required 1.5 nmi stagger distance, radar separation would not be maintained prior to the aircraft being established on their final approach course. The reduced separation standard for the staggered approach only applies once both aircraft are established on their final approach course. Effectively the aircraft had to have a 3 nmi stagger distance as they turned on to their final approach course, but 1.7 nmi stagger distance as they landed. This led them to speed up significantly to try and achieve the 1.7 nmi spacing that was used for stagger operations. This was operationally unacceptable and would lead to instabilities for a string of aircraft. This was not a problem for the further separated runways which require 2 nmi stagger spacing as the 2 nmi plus the separation between the runways achieved the 3 nmi radar separation requirement. The possible solutions would be to either provide vertical separation before the aircraft were established on their final approach course or adjust the stagger spacing to support the 3 nmi lateral separation. The former is how operations are generally handled in today's operations but would require one of the aircraft to fly a low, level segment and would lose much of the benefits the OPD was providing. The latter option was chosen and a stagger spacing of 2.1 nmi was used.

b. Alterations to the Schedule

At the beginning of the experiment, it was intended to test whether or not the time of assignment of the stagger target was important. It was identified as stagger, rather than secondary, because a secondary aircraft may be an in-trail aircraft, and it was assumed that the in-trail aircraft would be relevant from the moment spacing was assigned. A stagger aircraft may not be within range for spacing operations until much later, however. Upon consideration of how this testing would be achieved, it was noted that assigning the stagger aircraft at a later time would change the arrival schedule of the affected aircraft if the stagger aircraft was also primary. This would then change the schedules of every aircraft behind the affected aircraft. This is the scheduling equivalent of pop-up traffic, and was designated an off-nominal condition. Testing of how ASTAR10 could manage pop-up traffic and schedule changes is a subject for further study.

c. Stagger Aircraft as the Primary Aircraft

At the beginning of the experiment, it was conceived that the stagger aircraft would typically be the secondary aircraft. One question was how easy it would be to identify when the stagger aircraft was the primary aircraft, as well as how frequently that occurred. In the production of the initial scenarios, it was noted that the stagger aircraft being the primary aircraft, while not the norm, was not unusual. As the experiment plan was developed and spacing standards were adjusted, this changed to the point that the majority of aircraft were seeing a stagger aircraft as their primary aircraft. Throughout the whole process, it was noted that the identification of primary and secondary aircraft could follow simple rules. In a time-based system, the calculations are simple. If the in-trail spacing command is more than twice the stagger spacing command, it is primary. If it is less than twice the stagger command, the stagger command is primary. In a distance-based system, this becomes more complicated; but because any individual airspace will have a finite set of spacing options, simple rules can be produced. For example, in the final scenarios, the stagger spacing commands were large enough that only the largest in-trail spacing command of 5 nmi was more than twice the stagger command. This meant that the stagger command was always primary unless the in-trail command was for 5 nmi, or a non-heavy aircraft following a heavy aircraft. Different stagger commands may change the transition point between in-trail and stagger spacing dominance, but would not lead to confusion, because any particular runway separation will have a set stagger command, and thus a set transition point.

In the process of analyzing this issue, another oddity was noticed. It is possible for both the in-trail aircraft and the stagger aircraft to produce the same ETA for the subject aircraft. This occurs due to a peculiar 4-aircraft structure depicted below in Figure 11:

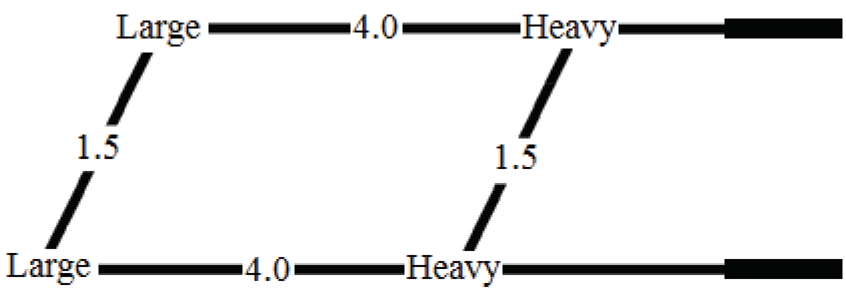

Figure 10: Even spacing configuration.

In the depicted configuration, the first heavy acts as a fixed ETA from which everything else can be judged. The second heavy and the first large have separate and unique ETAs for their primaries and secondaries, but the second large will see the same ETA for both of them. This can be logically deduced by noting that the distance from the first heavy to the second large is the same whether taken through the second heavy or the first large. A standard should be developed for which command will take precedence, and any visualization system may need to take account of this oddity, as any visual tracking of the current spacing target may result in rapid and frequent transitions from one target to another, which could prove distracting to pilots.

d. Schedule Sensitivity

In the original experiment plan, it was intended that time-based spacing be used for both in-trail and stagger spacing requirements. This proved problematic as the current ASTAR algorithm requires a distance-based spacing for stagger aircraft on final approach. Time-based spacing uses a single assumed FAS for all aircraft, as the calculation is done at the scheduling stage. By contrast, distance-based spacing allows ASTAR to use each aircraft's own FAS in the scenario. The conversion from one to the other inevitably produced sizable errors. Individual aircraft could cope with these errors, but the effect became cumulative, with each aircraft facing not just its own error, but also the errors of all aircraft in front of it. In implementing this distance-based spacing, it was noted that the initial stagger spacing and the final approach stagger spacing required two different spacing commands. The initial command calculated a distance-to-go or in-trail-equivalent spacing, while the second command calculated direct-line spacing. This difference produced substantial errors in the initial tests, leaving aircraft with as much as 9 seconds to make up in final approach, with the cumulative effects exceeding the capability of following aircraft to make up. When noticeable errors persisted, more in-depth analysis showed the remaining problem was schedule-based. The schedule was such that aircraft were being delivered to the airspace too slowly, so that by the time one aircraft appeared, its lead aircraft was already too far ahead to be caught up to. The problem was traced to the assumed FAS, which was still used in scheduling calculations for all spacing commands. The initially assumed FAS of 130 kt was slower than the average FAS in the simulation, so the ‘average’ aircraft saw an error. In attempting to find a better assumed FAS, it was noted that variations as small as 1 kt produced substantial changes in the behavior of the traffic stream across the full 100 aircraft. The final solution was a FAS of 139 kt, with wind influencing the schedule for appropriate scenarios. This still was not without error, however, as the A319s in the simulation still occasionally violated separation even with a half-mile buffer zone, resulting in a total of 33 violations out of 4752. These were caused by A319 final approach speeds in the range of 124 kt, 15 kt slower than the assumed FAS, resulting in the same time spacing command being converted into substantially lower distance spacing (4.85 nmi vs. 5.5 nmi). In future research, it is suggested that scheduling use final approach speeds based on individual aircraft types.

8. Conclusions

This experiment was conducted in an effort to refine and test the ASTAR10 algorithm and the underlying concept of operations. During the development of this experiment, a number of software and integration errors were detected and resolved. The issue of time-based spacing versus distance-based spacing was also highlighted for further discussion. Additionally, several questions as to the performance of the algorithm, such as how it would meet the radar separation requirement, what impact alterations to the spacing schedule would have, and how frequent and obvious the stagger aircraft being the primary aircraft would be, were addressed. Finally, ASTAR10 was validated and the use of a secondary target was shown to be important for performance, though not as important as had initially been thought.

Appendix A

List of Acronyms

APS - Airborne Precision Spacing

ASDO - Airspace Super-Density Operations

ASTAR - Airborne Spacing for Terminal Arrival Routes

ATA - actual time of arrival

ATC - Air Traffic Control

ATOL - Air Traffic Operations Lab

CMF - Cockpit Motion Facility

DPA - Dependent Parallel Arrivals

ETA- Estimated Time of Arrival

FAS - final approach speed

HITL- human-in-the-loop

KDFW - Dallas-Ft. Worth International Airport

LaRC - NASA Langley Research Center

NAS - National Airspace System

NLR - National Aerospace Laboratory (Netherlands)

OPD - Optimized Profile Descents

Appendix B

Validation Data

Run2-1-1	ATA	DTime	Run2-2-1	ATA	DTime	Run2-1-2	ATA	DTime	Run2-2-2	ATA	DTime
BGD0002	1922.25	41.5	BGD0002	1913	44.5	BGD0002	1922.5	42.5	BGD0002	1910.75	42
AEX0003	1974	51.75	AEX0003	1961.5	48.5	AEX0003	1974.25	51.75	AEX0003	1963	52.25
ABI0004	2061.75	87.75	INK0004	2052.25	90.75	ABI0004	2062.75	88.5	INK0004	2049.25	86.25
FSM0005	2114	52.25	AEX0005	2105	52.75	FSM0005	2114.25	51.5	AEX0005	2102.75	53.5
INK0006	2168	54	ABI0006	2166.25	61.25	INK0006	2170	55.75	ABI0006	2164.75	62
AEX0007	2251.75	83.75	FSM0007	2218.75	52.5	AEX0007	2249.5	79.5	FSM0007	2217	52.25
BGD0008	2307.25	55.5	ABI0008	2270	51.25	BGD0008	2308	58.5	ABI0008	2268.75	51.75
AEX0009	2369.25	62	FSM0009	2322.75	52.75	AEX0009	2370.25	62.25	FSM0009	2321.75	53
BGD0010	2426.75	57.5	INK0010	2376.5	53.75	BGD0010	2427.25	57	INK0010	2376.5	54.75
AEX0011	2478.25	51.5	FSM0011	2428.75	52.25	AEX0011	2478.25	51	FSM0011	2427.75	51.25
BGD0012	2533.75	55.5	INK0012	2486.25	57.5	BGD0012	2534.25	56	INK0012	2483.75	56
FSM0013	2618.75	85	AEX0013	2537.25	51	FSM0013	2618	83.75	AEX0013	2536	52.25
ABI0014	2675	56.25	ABI0014	2592.5	55.25	ABI0014	2674.5	56.5	ABI0014	2590.75	54.75
AEX0015	2727.5	52.5	FSM0015	2644.25	51.75	AEX0015	2727.75	53.25	FSM0015	2643	52.25
INK0016	2811.25	83.75	BGD0016	2735.5	91.25	INK0016	2811	83.25	BGD0016	2733.75	90.75
FSM0017	2866	54.75	FSM0017	2785.5	50	FSM0017	2866	55	FSM0017	2783	49.25
INK0018	2929	63	ABI0018	2841.5	56	INK0018	2931.75	65.75	ABI0018	2839.5	56.5
FSM0019	2982.25	53.25	AEX0019	2926.5	85	FSM0019	2982.75	51	AEX0019	2925.75	86.25
BGD0020	3039.5	57.25	ABI0020	2981	54.5	BGD0020	3039.25	56.5	ABI0020	2981.5	55.75
AEX0021	3098.25	58.75	FSM0021	3035	54	AEX0021	3094	54.75	FSM0021	3034.5	53
BGD0022	3155.5	57.25	BGD0022	3122.25	87.25	BGD0022	3155.25	61.25	BGD0022	3121.75	87.25
AEX0023	3214.5	59	AEX0023	3176	53.75	AEX0023	3214.5	59.25	AEX0023	3174.75	53
BGD0024	3272.25	57.75	BGD0024	3233.5	57.5	BGD0024	3273.75	59.25	BGD0024	3231.25	56.5
FSM0025	3323	50.75	FSM0025	3313.75	80.25	FSM0025	3324.25	50.5	FSM0025	3313.5	82.25
BGD0026	3377.5	54.5	BGD0026	3371.5	57.75	BGD0026	3379.25	55	BGD0026	3372.5	59
FSM0027	3427	49.5	AEX0027	3435.75	64.25	FSM0027	3428.75	49.5	AEX0027	3437.5	65
INK0028	3487.5	60.5	BGD0028	3486.5	50.75	INK0028	3488.25	59.5	BGD0028	3490.75	53.25
AEX0029	3538.25	50.75	AEX0029	3541.5	55	AEX0029	3538.75	50.5	AEX0029	3541.75	51
BGD0030	3595.25	57	BGD0030	3597.75	56.25	BGD0030	3596	57.25	BGD0030	3597.25	55.5
FSM0031	3647.5	52.25	AEX0031	3649	51.25	FSM0031	3647.75	51.75	AEX0031	3648.75	51.5
BGD0032	3703.5	56	BGD0032	3706	57	BGD0032	3704.25	56.5	BGD0032	3706	57.25
AEX0033	3751.25	47.75	AEX0033	3756.75	50.75	AEX0033	3755.75	51.5	AEX0033	3757.25	51.25
BGD0034	3838.75	87.5	BGD0034	3845	88.25	BGD0034	3840.75	85	BGD0034	3846.25	89
AEX0035	3888.75	50	FSM0035	3898.75	53.75	AEX0035	3892.75	52	FSM0035	3900	53.75
ABI0036	3954.75	66	INK0036	3954.75	56	ABI0036	3959	66.25	INK0036	3955.25	55.25
FSM0037	4008.5	53.75	AEX0037	4005.25	50.5	FSM0037	4010	51	AEX0037	4005.25	50
ABI0038	4063.75	55.25	BGD0038	4058.75	53.5	ABI0038	4065.5	55.5	BGD0038	4059.5	54.25
FSM0039	4114.25	50.5	FSM0039	4111.75	53	FSM0039	4117.5	52	FSM0039	4112.5	53

BGD0040	4183.25	69	BGD0040	4168.5	56.75	BGD0040	4183.75	66.25	BGD0040	4168.5	56
FSM0041	4235.75	52.5	FSM0041	4218.5	50	FSM0041	4236	52.25	FSM0041	4215.5	47
ABI0042	4299.5	63.75	BGD0042	4274	55.5	ABI0042	4301.25	65.25	BGD0042	4275.5	60
AEX0043	4375.25	75.75	FSM0043	4337	63	AEX0043	4377.25	76	FSM0043	4336	60.5
BGD0044	4430.75	55.5	INK0044	4393	56	BGD0044	4434.25	57	INK0044	4391.5	55.5
AEX0045	4483.75	53	AEX0045	4445	52	AEX0045	4483.75	49.5	AEX0045	4444.25	52.75
BGD0046	4569.5	85.75	BGD0046	4510.25	65.25	BGD0046	4572.25	88.5	BGD0046	4509.5	65.25
FSM0047	4624.5	55	AEX0047	4556.75	46.5	FSM0047	4623.75	51.5	AEX0047	4555.75	46.25
INK0048	4679	54.5	BGD0048	4624	67.25	INK0048	4677.25	53.5	BGD0048	4623.25	67.5
FSM0049	4764.75	85.75	FSM0049	4678.5	54.5	FSM0049	4763.25	86	FSM0049	4677.75	54.5
INK0050	4820.5	55.75	BGD0050	4765.25	86.75	INK0050	4820.25	57	BGD0050	4765	87.25
AEX0051	4871.75	51.25	AEX0051	4818.25	53	AEX0051	4872.5	52.25	AEX0051	4817.75	52.75
BGD0052	4928.25	56.5	ABI0052	4881.25	63	BGD0052	4928.75	56.25	ABI0052	4880.75	63
FSM0053	4978.5	50.25	AEX0053	4956.25	75	FSM0053	4979.5	50.75	AEX0053	4956.5	75.75
ABI0054	5033.75	55.25	BGD0054	5013	56.75	ABI0054	5035	55.5	BGD0054	5013	56.5
AEX0055	5087.25	53.5	AEX0055	5064.25	51.25	AEX0055	5089.75	54.75	AEX0055	5065.75	52.75
ABI0056	5149.75	62.5	BGD0056	5120.75	56.5	ABI0056	5152.25	62.5	BGD0056	5122.75	57
FSM0057	5202.5	52.75	FSM0057	5180	59.25	FSM0057	5204.25	52	FSM0057	5181	58.25
BGD0058	5259	56.5	INK0058	5239.25	59.25	BGD0058	5260.75	56.5	INK0058	5239	58
FSM0059	5339.75	80.75	FSM0059	5323.25	84	FSM0059	5341.25	80.5	FSM0059	5324.75	85.75
BGD0060	5398.25	58.5	ABI0060	5382	58.75	BGD0060	5402.5	61.25	ABI0060	5380.5	55.75
AEX0061	5458.5	60.25	FSM0061	5432.5	50.5	AEX0061	5460.75	58.25	FSM0061	5432	51.5
BGD0062	5514	55.5	BGD0062	5489	56.5	BGD0062	5518.25	57.5	BGD0062	5488.25	56.25
FSM0063	5575.75	61.75	AEX0063	5540.5	51.5	FSM0063	5577.25	59	AEX0063	5540.25	52
BGD0064	5634.5	58.75	BGD0064	5604	63.5	BGD0064	5635	57.75	BGD0064	5604.75	64.5
FSM0065	5685	50.5	FSM0065	5654	50	FSM0065	5686	51	FSM0065	5656	51.25
BGD0066	5772.75	87.75	BGD0066	5711.75	57.75	BGD0066	5773	87	BGD0066	5713.25	57.25
AEX0067	5826	53.25	AEX0067	5770.25	58.5	AEX0067	5826.5	53.5	AEX0067	5767.75	54.5
BGD0068	5878	52	ABI0068	5847.5	77.25	BGD0068	5879	52.5	ABI0068	5846.5	78.75
FSM0069	5933.25	55.25	AEX0069	5898.5	51	FSM0069	5933.75	54.75	AEX0069	5900.75	54.25
ABI0070	5997	63.75	BGD0070	5963.25	64.75	ABI0070	5999.5	65.75	BGD0070	5966.5	65.75
AEX0071	6047.75	50.75	FSM0071	6016.25	53	AEX0071	6052	52.5	FSM0071	6019.5	53
INK0072	6136.25	88.5	BGD0072	6104.5	88.25	INK0072	6140.25	88.25	BGD0072	6105.25	85.75
FSM0073	6189.75	53.5	FSM0073	6157.25	52.75	FSM0073	6195	54.75	FSM0073	6158.5	53.25
BGD0074	6246.25	56.5	BGD0074	6215.5	58.25	BGD0074	6251	56	BGD0074	6218.25	59.75
FSM0075	6298.25	52	FSM0075	6278.25	62.75	FSM0075	6300.75	49.75	FSM0075	6279.25	61
BGD0076	6355	56.75	INK0076	6335.75	57.5	BGD0076	6356	55.25	INK0076	6334.5	55.25
AEX0077	6405.75	50.75	FSM0077	6423.25	87.5	AEX0077	6407.25	51.25	FSM0077	6422.5	88
BGD0078	6472	66.25	BGD0078	6476.25	53	BGD0078	6474.75	67.5	BGD0078	6476	53.5
FSM0079	6522	50	AEX0079	6527	50.75	FSM0079	6524.75	50	AEX0079	6526.75	50.75
BGD0080	6578.25	56.25	BGD0080	6586.5	59.5	BGD0080	6580.75	56	BGD0080	6585	58.25
FSM0081	6638.5	60.25	FSM0081	6635.25	48.75	FSM0081	6642	61.25	FSM0081	6634	49
BGD0082	6697	58.5	INK0082	6690.75	55.5	BGD0082	6697.5	55.5	INK0082	6688.5	54.5

FSM0083	6784	87	FSM0083	6742	51.25	FSM0083	6784.25	86.75	FSM0083	6740.5	52
INK0084	6838.5	54.5	BGD0084	6798.5	56.5	INK0084	6838.25	54	BGD0084	6796.5	56
AEX0085	6890.5	52	AEX0085	6883	84.5	AEX0085	6891.25	53	AEX0085	6881	84.5
BGD0086	6947.25	56.75	INK0086	6937.75	54.75	BGD0086	6946.75	55.5	INK0086	6936.25	55.25
FSM0087	6996.75	49.5	FSM0087	6989.75	52	FSM0087	6995.5	48.75	FSM0087	6988.75	52.5
ABI0088	7051.75	55	ABI0088	7054.5	64.75	ABI0088	7053.75	58.25	ABI0088	7050	61.25
AEX0089	7112.25	60.5	FSM0089	7106.5	52	AEX0089	7114.75	61	FSM0089	7105.5	55.5
BGD0090	7167.5	55.25	ABI0090	7161.5	55	BGD0090	7171.5	56.75	ABI0090	7162.25	56.75
FSM0091	7218.75	51.25	FSM0091	7215.5	54	FSM0091	7222.25	50.75	FSM0091	7216	53.75
BGD0092	7283.75	65	BGD0092	7300.75	85.25	BGD0092	7289	66.75	BGD0092	7301.5	85.5
FSM0093	7335	51.25	AEX0093	7351.75	51	FSM0093	7336	47	AEX0093	7352.75	51.25
INK0094	7401	66	BGD0094	7416.5	64.75	INK0094	7406.5	70.5	BGD0094	7416.5	63.75
FSM0095	7454.25	53.25	FSM0095	7472.25	55.75	FSM0095	7454.25	47.75	FSM0095	7472.75	56.25
INK0096	7542.75	88.5	BGD0096	7558.25	86	INK0096	7547.25	93	BGD0096	7559	86.25
FSM0097	7592.5	49.75	FSM0097	7611.25	53	FSM0097	7599	51.75	FSM0097	7611.75	52.75
ABI0098	7650.5	58	INK0098	7672	60.75	ABI0098	7651.75	52.75	INK0098	7672.5	60.75
FSM0099	7704.25	53.75	FSM0099	7720.25	48.25	FSM0099	7706	54.25	FSM0099	7722	49.5
FSM0100	7783	78.75	FSM0100	7864.75	144.5	FSM0100	7785.5	79.5	FSM0100	7866.75	144.75

Run4-1-1	ATA	DTime	Run4-2-1	ATA	DTime	Run4-1-2	ATA	DTime	Run4-2-2	ATA	DTime
BGD0002	1932.5	52	BGD0002	1920.75	52	BGD0002	1932	51.5	BGD0002	1921.5	53
AEX0003	1983.75	51.25	AEX0003	1971.5	50.75	AEX0003	1983	51	AEX0003	1971.25	49.75
ABI0004	2076	92.25	INK0004	2065.25	93.75	ABI0004	2075.5	92.5	INK0004	2065	93.75
FSM0005	2128.25	52.25	AEX0005	2124.5	59.25	FSM0005	2128.5	53	AEX0005	2124.5	59.5
INK0006	2178.5	50.25	ABI0006	2181.25	56.75	INK0006	2178.75	50.25	ABI0006	2181.5	57
AEX0007	2270.75	92.25	FSM0007	2234.5	53.25	AEX0007	2271.25	92.5	FSM0007	2234.75	53.25
BGD0008	2322	51.25	ABI0008	2286.75	52.25	BGD0008	2322.5	51.25	ABI0008	2288	53.25
AEX0009	2387.25	65.25	FSM0009	2338.5	51.75	AEX0009	2387.5	65	FSM0009	2339	51
BGD0010	2440	52.75	INK0010	2397.75	59.25	BGD0010	2439.25	51.75	INK0010	2398.25	59.25
AEX0011	2491.75	51.75	FSM0011	2446.25	48.5	AEX0011	2492.5	53.25	FSM0011	2446.75	48.5
BGD0012	2543.5	51.75	INK0012	2500.5	54.25	BGD0012	2544	51.5	INK0012	2500.75	54
FSM0013	2634	90.5	AEX0013	2557.5	57	FSM0013	2634.75	90.75	AEX0013	2557.5	56.75
ABI0014	2683	49	ABI0014	2609	51.5	ABI0014	2687.25	52.5	ABI0014	2609.25	51.75
AEX0015	2739	56	FSM0015	2659.75	50.75	AEX0015	2742.75	55.5	FSM0015	2660.5	51.25
INK0016	2825.75	86.75	BGD0016	2754.25	94.5	INK0016	2831.25	88.5	BGD0016	2754.5	94
FSM0017	2881.5	55.75	FSM0017	2806.75	52.5	FSM0017	2886.5	55.25	FSM0017	2808.25	53.75
INK0018	2943.75	62.25	ABI0018	2859.75	53	INK0018	2948	61.5	ABI0018	2860	51.75
FSM0019	2994.25	50.5	AEX0019	2949	89.25	FSM0019	2998.25	50.25	AEX0019	2950	90
BGD0020	3048	53.75	ABI0020	3003.75	54.75	BGD0020	3052	53.75	ABI0020	3004.75	54.75
AEX0021	3110.75	62.75	FSM0021	3055.75	52	AEX0021	3114.75	62.75	FSM0021	3056.75	52
BGD0022	3160	49.25	BGD0022	3147.75	92	BGD0022	3165	50.25	BGD0022	3148.75	92
AEX0023	3226	66	AEX0023	3196	48.25	AEX0023	3231.5	66.5	AEX0023	3197.5	48.75
BGD0024	3287	61	BGD0024	3258.25	62.25	BGD0024	3293	61.5	BGD0024	3259.25	61.75
FSM0025	3339.5	52.5	FSM0025	3338	79.75	FSM0025	3345.75	52.75	FSM0025	3340.25	81

BGD0026	3394	54.5	BGD0026	3391.75	53.75	BGD0026	3399.5	53.75	BGD0026	3392.5	52.25
FSM0027	3450	56	AEX0027	3456	64.25	FSM0027	3454.5	55	AEX0027	3458.25	65.75
INK0028	3510.25	60.25	BGD0028	3505.5	49.5	INK0028	3514.75	60.25	BGD0028	3507.5	49.25
AEX0029	3564.75	54.5	AEX0029	3559.75	54.25	AEX0029	3568.5	53.75	AEX0029	3561.25	53.75
BGD0030	3619	54.25	BGD0030	3612.75	53	BGD0030	3622.5	54	BGD0030	3613.25	52
FSM0031	3675	56	AEX0031	3665.75	53	FSM0031	3679.25	56.75	AEX0031	3665.5	52.25
BGD0032	3727.75	52.75	BGD0032	3715.75	50	BGD0032	3732.25	53	BGD0032	3718	52.5
AEX0033	3785.5	57.75	AEX0033	3770.25	54.5	AEX0033	3789	56.75	AEX0033	3771.5	53.5
BGD0034	3871	85.5	BGD0034	3860	89.75	BGD0034	3875	86	BGD0034	3862	90.5
AEX0035	3922.75	51.75	FSM0035	3917	57	AEX0035	3926.5	51.5	FSM0035	3918.75	56.75
ABI0036	3987.5	64.75	INK0036	3974.5	57.5	ABI0036	3991.75	65.25	INK0036	3977	58.25
FSM0037	4039.5	52	AEX0037	4026.25	51.75	FSM0037	4042.5	50.75	AEX0037	4027.75	50.75
ABI0038	4089.5	50	BGD0038	4077.75	51.5	ABI0038	4092.75	50.25	BGD0038	4078.75	51
FSM0039	4139.25	49.75	FSM0039	4129.25	51.5	FSM0039	4143	50.25	FSM0039	4130.5	51.75
BGD0040	4205.5	66.25	BGD0040	4180.25	51	BGD0040	4207.75	64.75	BGD0040	4181	50.5
FSM0041	4255.25	49.75	FSM0041	4230.75	50.5	FSM0041	4258	50.25	FSM0041	4231.5	50.5
ABI0042	4321.5	66.25	BGD0042	4283.25	52.5	ABI0042	4324.25	66.25	BGD0042	4281.75	50.25
AEX0043	4397.75	76.25	FSM0043	4348	64.75	AEX0043	4400.5	76.25	FSM0043	4348	66.25
BGD0044	4447.25	49.5	INK0044	4401	53	BGD0044	4450.25	49.75	INK0044	4399.25	51.25
AEX0045	4497	49.75	AEX0045	4457.5	56.5	AEX0045	4500	49.75	AEX0045	4456.25	57
BGD0046	4589.5	92.5	BGD0046	4519.25	61.75	BGD0046	4592.25	92.25	BGD0046	4517.25	61
FSM0047	4643.25	53.75	AEX0047	4573.5	54.25	FSM0047	4643.25	51	AEX0047	4570.75	53.5
INK0048	4692.75	49.5	BGD0048	4638.75	65.25	INK0048	4693.25	50	BGD0048	4634.75	64
FSM0049	4785.5	92.75	FSM0049	4690.5	51.75	FSM0049	4785.5	92.25	FSM0049	4687.25	52.5
INK0050	4840.75	55.25	BGD0050	4783	92.5	INK0050	4841.5	56	BGD0050	4777	89.75
AEX0051	4893	52.25	AEX0051	4834.75	51.75	AEX0051	4893.25	51.75	AEX0051	4829.25	52.25
BGD0052	4942.5	49.5	ABI0052	4900.5	65.75	BGD0052	4943	49.75	ABI0052	4894.75	65.5
FSM0053	4994.5	52	AEX0053	4977	76.5	FSM0053	4995.25	52.25	AEX0053	4972	77.25
ABI0054	5047	52.5	BGD0054	5033.5	56.5	ABI0054	5047.5	52.25	BGD0054	5027.5	55.5
AEX0055	5099.5	52.5	AEX0055	5088	54.5	AEX0055	5100.25	52.75	AEX0055	5084	56.5
ABI0056	5164	64.5	BGD0056	5145.75	57.75	ABI0056	5164.25	64	BGD0056	5143	59
FSM0057	5218.5	54.5	FSM0057	5205.25	59.5	FSM0057	5218.25	54	FSM0057	5201.5	58.5
BGD0058	5280.5	62	INK0058	5261.25	56	BGD0058	5280.25	62	INK0058	5259.5	58
FSM0059	5361.75	81.25	FSM0059	5348.25	87	FSM0059	5361	80.75	FSM0059	5345.25	85.75
BGD0060	5416.5	54.75	ABI0060	5403.75	55.5	BGD0060	5415.5	54.5	ABI0060	5402	56.75
AEX0061	5478	61.5	FSM0061	5454.5	50.75	AEX0061	5476.5	61	FSM0061	5453	51
BGD0062	5530	52	BGD0062	5505	50.5	BGD0062	5528.25	51.75	BGD0062	5503.25	50.25
FSM0063	5594	64	AEX0063	5560	55	FSM0063	5592.5	64.25	AEX0063	5558.5	55.25
BGD0064	5647.25	53.25	BGD0064	5621.5	61.5	BGD0064	5646	53.5	BGD0064	5619.25	60.75
FSM0065	5701	53.75	FSM0065	5676.25	54.75	FSM0065	5700.75	54.75	FSM0065	5674.75	55.5
BGD0066	5790.5	89.5	BGD0066	5727	50.75	BGD0066	5788.75	88	BGD0066	5726	51.25
AEX0067	5855	64.5	AEX0067	5792.5	65.5	AEX0067	5853.75	65	AEX0067	5791.5	65.5
BGD0068	5904.75	49.75	ABI0068	5869.25	76.75	BGD0068	5904	50.25	ABI0068	5869.25	77.75

FSM0069	5956.75	52	AEX0069	5923	53.75	FSM0069	5956.75	52.75	AEX0069	5923.75	54.5
ABI0070	6021.75	65	BGD0070	5986.5	63.5	ABI0070	6021	64.25	BGD0070	5988.25	64.5
AEX0071	6072.75	51	FSM0071	6040.25	53.75	AEX0071	6072.5	51.5	FSM0071	6040.25	52
INK0072	6165.5	92.75	BGD0072	6130.75	90.5	INK0072	6165	92.5	BGD0072	6131.25	91
FSM0073	6228.25	62.75	FSM0073	6181.75	51	FSM0073	6227.5	62.5	FSM0073	6182.5	51.25
BGD0074	6288.5	60.25	BGD0074	6234.5	52.75	BGD0074	6287.75	60.25	BGD0074	6232.75	50.25
FSM0075	6338.25	49.75	FSM0075	6298.25	63.75	FSM0075	6338.25	50.5	FSM0075	6298.5	65.75
BGD0076	6386.25	48	INK0076	6351.5	53.25	BGD0076	6387.25	49	INK0076	6350	51.5
AEX0077	6434	47.75	FSM0077	6442.5	91	AEX0077	6437.25	50	FSM0077	6442	92
BGD0078	6502	68	BGD0078	6494	51.5	BGD0078	6504.25	67	BGD0078	6492.5	50.5
FSM0079	6549.75	47.75	AEX0079	6545.5	51.5	FSM0079	6553.75	49.5	AEX0079	6544	51.5
BGD0080	6599.25	49.5	BGD0080	6605.5	60	BGD0080	6605.25	51.5	BGD0080	6605.5	61.5
FSM0081	6666	66.75	FSM0081	6656.25	50.75	FSM0081	6670	64.75	FSM0081	6656.5	51
BGD0082	6717.75	51.75	INK0082	6710	53.75	BGD0082	6722	52	INK0082	6710.25	53.75
FSM0083	6809.25	91.5	FSM0083	6761.25	51.25	FSM0083	6812.75	90.75	FSM0083	6761.5	51.25
INK0084	6866.25	57	BGD0084	6813.25	52	INK0084	6870	57.25	BGD0084	6813.75	52.25
AEX0085	6922.75	56.5	AEX0085	6903.5	90.25	AEX0085	6927.5	57.5	AEX0085	6903.75	90
BGD0086	6974.25	51.5	INK0086	6957	53.5	BGD0086	6981.75	54.25	INK0086	6957	53.25
FSM0087	7027	52.75	FSM0087	7010.75	53.75	FSM0087	7035.75	54	FSM0087	7010.75	53.75
ABI0088	7076	49	ABI0088	7072.75	62	ABI0088	7087.75	52	ABI0088	7073.5	62.75
AEX0089	7141.75	65.75	FSM0089	7126	53.25	AEX0089	7152.25	64.5	FSM0089	7126.25	52.75
BGD0090	7188.75	47	ABI0090	7180.25	54.25	BGD0090	7201.75	49.5	ABI0090	7180.25	54
FSM0091	7240	51.25	FSM0091	7237.5	57.25	FSM0091	7254.5	52.75	FSM0091	7237	56.75
BGD0092	7304	64	BGD0092	7323.75	86.25	BGD0092	7318.5	64	BGD0092	7323.25	86.25
FSM0093	7354.5	50.5	AEX0093	7374.25	50.5	FSM0093	7369.75	51.25	AEX0093	7373.75	50.5
INK0094	7421.5	67	BGD0094	7441	66.75	INK0094	7437.5	67.75	BGD0094	7440.5	66.75
FSM0095	7473.25	51.75	FSM0095	7497.75	56.75	FSM0095	7490.75	53.25	FSM0095	7497.5	57
INK0096	7564.75	91.5	BGD0096	7585.25	87.5	INK0096	7581.75	91	BGD0096	7585.5	88
FSM0097	7621.75	57	FSM0097	7638.5	53.25	FSM0097	7639	57.25	FSM0097	7638.5	53
ABI0098	7672	50.25	INK0098	7699.5	61	ABI0098	7690.5	51.5	INK0098	7700.25	61.75
FSM0099	7729	57	FSM0099	7747.75	48.25	FSM0099	7749.25	58.75	FSM0099	7748	47.75
FSM0100	7806.75	77.75	FSM0100	7891.5	143.75	FSM0100	7827.25	78	FSM0100	7891.75	143.75

Appendix C

Separation Violations

Separation Violations	1-1	2-1	1-2	2-2
Run 1	0	0	0	0
Run 2	0	0	0	0
Run 4	0	0	0	0
Run 5	0	0	0	0
Run 6	0	0	0	0
Run 7	0	0	0	0
Run 8	0	0	0	0
Run 9	0	0	0	0
Run 10	0	0	0	0
Run 11	0	0	0	0
Run 12	0	0	0	0
Run 13	0	1	0	1
Run 14	0	0	0	0
Run 15	0	1	0	1

Appendix D

Commanded Speed Changes

SpdChanges(total)	1-1	2-1	1-2	2-2
Run 1	669	690	672	686
Run 2	678	664	658	664
Run 4	747	698	843	693
Run 5	858	732	862	729
Run 6	1284	1245	1274	1310
Run 7	869	835	869	835
Run 8	1488	1429	1479	1445
Run 9	1288	1264	1288	1264
Run 10	737	671	736	696
Run 11	844	830	844	830
Run 12	1323	1029	1316	1029
Run 13	1133	1134	1133	1134
Run 14	1496	1440	1504	1448
Run 15	1252	1237	1252	1237

Appendix E

CrossingTimeError

4-1-1	4-2-1	4-1-2	4-2-2	5-1-1	5-1-2	5-2-1	5-2-2	6-1-1	6-1-2	6-2-1	6-2-2
0.5	-0.25	0.25	-0.25	0.5	-0.5	1.25	0	0.5	0	0.5	0.75
-0.628	-0.534	-1.108	0.328	-0.145	1.645	0.022	2.259	0.144	-0.83	0.097	1.237
-0.024	-0.934	-0.14	-1.743	-0.605	-0.707	-0.699	-1.312	-0.502	-0.691	-1.314	-0.689
0.85	1.85	0.85	0.85	0.85	0.85	1.1	0.85	0.36	1.11	0.86	0.86
0.911	0.572	1.5	0.866	0.609	0.4	1.013	0.204	-0.38	0.024	0.351	-0.071
-0.226	-0.498	-0.008	0	0.002	-1.083	0.07	-1.364	-2.018	0.12	-1.364	0.62
-0.15	-0.059	0.1	0.111	0.1	-0.737	-0.15	-0.508	-0.64	0.436	-1.14	0.564
-0.89	-0.14	-0.778	0.561	-0.467	-0.93	-0.247	-0.929	-1.362	-1.007	-1.107	-0.969
0	-0.412	0	-0.953	0	-1.385	0	-1.737	0.62	-1.121	0.62	-1.151
1.248	0.218	0.622	0.242	0	0.042	0.5	0.062	0.32	-0.019	0.155	0.112
0.042	-2.052	1.564	-2.046	1.368	-1.407	0.95	-1.177	0.59	-1.082	-1.07	-0.911
1.282	-0.29	0.697	-0.594	2.543	-0.622	1.712	-1.092	-0.901	-0.53	-1.527	-0.522
-0.15	-0.575	-0.4	-0.654	-0.15	-0.739	-0.15	-0.6	0.36	-0.116	0.36	0.358
-2.182	0.194	1.233	0.282	1.07	-1.435	0.359	-1.104	-0.953	-1.51	-2.616	-1.024
0.881	-0.356	0.334	-0.038	0.375	-0.507	0.312	-0.323	0.153	0.159	-0.455	-0.067
0.1	3.1	1.35	3.1	0.85	1.6	1.1	2.85	0.11	1.36	0.36	1.36
1.466	0.373	1.426	0.989	1.423	1.15	1.309	0.652	0.532	-0.51	0.387	-0.734
1.5	-0.017	0	-1.094	0.412	0.424	-0.783	-0.039	0.62	-0.145	0.62	-0.687
-0.672	-0.4	-0.401	-0.65	-0.219	-0.65	-0.206	-0.4	-0.015	-0.39	0.012	-1.14
0.113	1.225	-0.111	0.984	1.691	0.961	1.718	0.776	-0.759	-0.052	-0.697	-0.107
0	0.22	0	0.225	-0.632	0.208	0.251	0.288	0.12	-1.204	-0.88	-0.783
-1.387	1.6	-0.753	1.6	0.06	1.6	-0.057	1.35	-0.791	0.86	-2.356	0.86
-1	-1.718	0	-0.955	-0.5	-0.353	0	-0.873	0.62	-2.013	0.12	-0.063
0.021	1.099	0.383	0.48	1.477	0.845	0.813	0.554	1.076	3.562	1.127	-0.523
-0.528	-0.65	-0.143	0.1	0.559	0.35	0.645	-0.15	-0.565	0.61	-0.331	0.61
0.681	0.379	0.07	-0.601	1.53	0.043	1.168	-0.714	-2.561	0.142	-1.378	0.025
2.854	1.5	1.838	1.5	0.25	-0.183	0.362	0.47	-0.304	2.988	-0.19	2.217
0.564	-1.994	0.359	-2.504	0.228	-1.824	0.349	-0.926	-1.361	-2.349	-1.173	-1.251
-0.606	-0.696	-1.352	-0.893	-0.314	-0.279	-1.716	-0.402	-1.096	-2.765	-1.121	-1.257
-0.683	1.254	-0.962	-0.055	-0.548	-0.572	-1.154	-0.436	-1.453	-1.451	-2.328	-0.364
0.079	0.338	0.419	0.042	-1.153	-1.292	-0.771	-0.74	-0.824	-2.14	-1.29	-1.065
-0.97	-0.94	-1.017	1.308	-2.397	-2.074	-1.418	-1.552	-3.346	-1.391	-2.161	-1.072
0.144	1.041	-0.492	-0.009	-0.829	-0.505	-0.983	-0.399	0.794	-0.727	0.41	0.133
0.6	1.6	0.35	1.6	0.6	1.85	0.6	0.85	1.11	-0.14	0.86	1.36
-0.132	1.081	-0.433	0.941	-1.019	0.372	-1.51	0.324	-0.012	0.301	-0.094	0.793
0	0.505	0	1.373	0	0.335	0	0.185	-0.38	-0.8	0.12	-0.337

0	0.22	-0.665	-0.703	-1.557	-0.124	-1.962	-0.127	1.379	-0.587	0.887	-0.442
-1.781	-1.318	-1.485	-1.827	-1.269	-0.491	-2.556	0.287	0.049	-2.915	0.138	0.169
-2.145	-0.266	-1.724	-0.125	-2.385	-1.786	-2.604	-2.089	1.002	-1.795	0.548	-0.901
-0.5	-1.238	-1.5	-1.64	-1	-1.687	-1.5	-1.183	1.12	-1.928	0.62	-1.426
-0.463	-1.296	0.139	-1.407	-1.404	-1.296	-1.185	-1.486	0.957	-1.052	-0.457	-1.358
-0.5	0.74	0	-1.465	-0.5	-0.28	0	-0.209	0.62	-1.751	1.12	-0.756
0.1	0.5	0.1	0	0.1	0	0.1	-0.5	-0.39	0.62	0.11	0.12
-0.799	1.061	-0.437	-0.081	-1.632	0.496	0.277	1.071	-2.083	-1.778	-0.297	-1.134
-0.751	1.935	-0.806	2.138	-1.111	1.348	-1.035	2.028	-1.686	0.721	-1.782	-0.031
-0.15	2	-0.4	1.5	-0.4	1.094	-0.15	0.624	-0.39	0.12	-0.64	-0.38
0.805	0.284	-1.39	-0.375	0.87	0.666	0.169	0.177	-0.567	0.986	-0.49	-0.503
-1.56	3	-1.185	1	-0.154	2	-0.871	1.5	-1.947	1.62	-1.84	1.12
-0.15	0.5	-0.4	0	-0.4	0	-0.15	0	0.11	1.62	-0.89	0.12
-0.179	1.6	0.053	-0.15	0.14	0.35	0.173	0.6	-1.444	-0.14	-1.473	0.11
-0.732	0.851	-0.776	1.043	-0.392	1.063	-0.901	0.943	-0.051	0.41	-0.341	-0.235
-0.868	1	-0.975	1	-0.868	1	0.12	0.5	-0.658	0.62	-2.949	0.12
0.511	-0.4	0.848	0.35	0.645	0.1	0.326	-0.15	-0.27	0.61	-0.741	0.36
0.676	1.566	0.631	0.311	1.005	1.071	1.513	2.513	-0.659	-0.101	-1.069	0.055
1.17	0.432	1.388	2.283	1.175	1.734	1.211	-0.411	0.332	0.251	0.056	-1.128
0.5	0.397	0	1.816	1	1.474	1.967	0.647	0.62	1.027	0.62	-3.076
0.679	1	0.241	1	1.128	-0.258	1.098	-1.132	-0.714	2.12	-0.596	0.62
1.236	-0.609	1.255	1.609	1.25	0.304	1.38	0.194	-1.132	1.097	-0.404	-0.853
0.6	0.35	0.1	1.1	0.35	0.35	0.6	0.1	1.11	0.86	1.11	0.36
0.018	0.382	-0.688	1.829	0.43	0.001	0.221	0.25	-0.644	0.504	-0.59	-0.246
0	0.172	-1	-0.25	0	0.161	0	0.008	-0.38	-0.192	0.12	-0.225
-0.486	-1.353	-0.55	-1.218	-0.046	-0.397	0.279	-0.176	-1.476	-0.707	-1.746	-1.079
-0.5	-0.204	-0.5	0	-0.5	-0.143	-0.5	-0.087	0.62	0.117	0.62	0.194
0.5	0	0.794	-0.5	1	0.181	1	-0.82	-0.048	0.62	-0.217	0.12
0.857	0	2.051	0	1.037	-0.5	0.774	-0.5	-1.684	0.62	-1.112	-0.38
0.6	-0.921	0.35	-0.419	0.35	-1.329	0.1	-1.189	0.11	0.543	-0.14	-1.933
3.017	0	3.425	0.5	1.803	0	1.173	0.5	1.439	0.12	0.593	0.62
-0.751	-0.15	-0.178	0.85	0.628	-0.4	0.171	-0.15	-1.294	0.11	-2.769	-0.14
0.331	-0.334	1.296	0.603	-0.001	0.428	0.011	0.048	-0.36	0.374	-1.553	1.234
0.5	0.5	0.5	2.5	1.5	0.027	1	0.465	0.62	0.12	-0.38	0.12
-0.685	1	-1	0	0.206	-0.5	0.177	0	0.125	-0.38	0.306	0.12
1.35	1.6	1.6	0.6	0.35	1.6	0.35	2.35	0.86	1.36	0.86	1.36
1.199	-0.043	1.332	-0.294	0.879	-0.197	0.899	-0.158	1.708	-0.905	1.387	-1.114
-0.781	1.163	-0.346	-0.997	0.17	-0.121	-0.284	-0.023	-0.838	-0.262	-1.629	-0.271
-1.589	0	-1.354	-0.5	-1.534	-0.5	-1.474	0	-1.207	1.12	-1.512	1.62
-2.79	0.5	-1.799	1	-1.541	0.5	-1.504	0.5	-3.849	-0.237	-3.259	-0.273
-3.846	1.6	-1.334	1.1	-1.395	0.85	-1.401	0.85	-2.302	1.61	-1.691	1.86

-1	-0.858	0.5	-1.081	-0.111	-0.372	-0.23	-0.121	-0.38	-0.658	-0.38	-1.593
-2.995	0.299	-0.727	0.254	-0.305	0.203	-1.394	0.212	0.642	-0.411	-0.654	-0.575
-3.453	-0.771	-1.398	0.186	-0.406	-0.066	-1.023	0.099	-2.288	-0.988	-4.231	0.089
-0.5	-1.309	0	-0.837	0	-2.034	0	-1.255	-0.38	-1.569	-0.88	-1.515
-1.258	0.359	-0.879	0.355	0.311	0	0.438	-0.694	-0.265	-0.222	0.027	-0.918
0.85	-0.29	0.35	-0.372	0.85	-0.756	0.35	-1.415	0.36	-0.093	0.86	-1.297
-0.12	-1.82	0.22	-1.575	0.537	-0.644	-0.379	-1.308	-0.256	0.301	0.256	0.032
-0.298	-0.15	0.487	-0.15	2.71	0.1	-0.136	0.1	0.619	-0.14	0.24	-0.14
-1.47	0.193	1.101	0.127	-0.024	0.363	0.197	-0.233	-0.567	-0.377	-3.289	-0.554
-1.046	-0.209	0.366	-0.303	0.181	-0.031	1.342	-0.501	0.598	0.344	-1.709	-0.22
-3.805	-1	-1.009	0	-1.338	-0.5	-0.69	-1	0.481	0.62	-1.914	-0.38
-1.5	0.222	0	-0.066	0	-0.18	0	0.317	0.62	1.546	-1.38	-0.179
-3.49	2.252	-0.632	2.25	-1.297	0.038	-1.113	-0.261	-1.522	-0.317	-0.758	-1.564
-1.286	0.743	-0.09	0.708	-0.405	0.852	0.442	1.839	-0.658	0.858	-1.555	0.779
-1	0.85	0.5	0.6	0.5	1.35	0.5	1.85	0.12	0.86	-0.88	0.86
0.146	-0.276	0.926	-0.182	0.202	-0.115	2.792	-1.24	-0.726	-0.714	-1.709	-0.841
1	0.5	2.5	0.5	0.5	0	1	0	0.62	0.62	-0.38	-0.38
0.237	0.72	2.171	0.669	1.424	1.179	1.438	1.851	0.09	1.167	-1.004	0.755
0.6	1.85	2.1	2.35	1.85	0.6	2.85	1.35	0.86	0.61	0.86	0.61
-0.313	-0.056	-0.051	-0.153	0.761	0.358	0.743	0.208	-0.013	-0.049	0.462	-0.32
-1.78	0.236	-0.734	1.013	0.165	0.393	0.737	1.507	-1.183	1.012	-3.319	1.405
0.501	-2.675	2.435	-3.573	0.607	-2.168	0.572	-1.453	0.147	-0.71	-0.134	-2.065
-0.2	1.1	0.3	1.35	0.3	1.1	-0.2	1.1	-0.26	1.36	-0.76	1.86

7-1-1	7-2-1	7-1-2	7-2-2	8-1-1	8-1-2	8-2-1	8-2-2	9-1-1	9-1-2	9-2-1	9-2-2
0.25	-0.25	0.502	-0.25	2.75	1.5	3.25	1	2.5	1	2.5	1.25
0.304	0.238	0.39	-0.435	-4.73	-0.399	-3.931	-3.165	-0.349	0.057	-1.235	-1.613
-1.181	-1.305	-1.361	-0.925	-1.953	-1.624	-1.601	-1.901	-0.131	-1.792	-2.067	-1.576
-0.39	0.61	-0.39	0.61	1.86	2.36	3.36	2.11	1.36	1.61	1.61	2.11
0.149	-0.215	0.234	-0.179	-2.585	0.359	0.625	0.836	1.384	0.886	1.33	0.602
-1.704	-1.747	-1.596	-1.701	-2.012	1.12	3.071	1.62	0.25	2.679	0.168	-0.083
-0.39	-1.23	-0.39	-1.447	1.36	-0.707	1.86	-0.568	1.36	0.451	1.36	2.214
-0.977	-2.311	-0.631	-1.233	0.655	-0.253	2.333	-0.296	-0.63	-0.572	0.335	-0.422
0.62	-2.522	0.62	-2.704	2.62	-0.927	3.62	-0.796	1.62	-0.609	2.12	-0.386
0.96	-0.18	0.715	-0.319	0.71	1.962	1.331	3.078	-0.756	-1.797	0.419	0.606
1.069	-2.086	1.232	-1.796	-0.352	2.429	-0.097	1.438	-2.007	2.736	-1.832	1.942
0.259	-1.027	0.491	0.057	-2.808	-1.424	0.016	-1.198	-2.628	-1.524	-2.619	-1.433
-0.14	-1.048	0.61	0.16	1.61	-2.094	1.86	-1.495	1.86	-3.743	1.61	-2.908
-1.262	-1.709	-0.613	-0.553	-2.424	-1.815	-1.574	-1.736	-2.077	0.01	-2.217	0.5
0.274	-1.032	0.176	0.092	1.499	0.794	-2.015	1.037	0.942	1.099	0.429	1.769
0.36	0.86	0.11	1.36	1.86	4.86	1.11	2.86	1.11	4.86	1.36	3.36
1.67	-0.677	1.363	0.258	0.408	-0.816	-0.593	-1.333	0.351	-0.66	0.436	-0.874

-0.331	-1.554	-0.303	-0.522	2.12	2.04	1.12	-0.283	-0.164	0.317	-0.204	-0.542
-1.004	-1.14	-1.015	-0.39	-1.703	1.61	-2.879	1.36	-1.344	1.36	-1.395	1.11
-0.59	-0.436	-0.476	0.341	-0.562	-1.959	-0.287	-1.285	0.015	0.73	0.009	0.202
0.12	-0.639	-0.38	-0.147	0.62	-1.486	1.12	-2.053	1.12	-0.821	1.12	-1.178
-0.431	0.11	0.035	0.11	-1.779	0.86	-3.187	1.86	0.648	1.11	-0.011	0.61
0.12	-0.512	0.62	1.262	0.62	-0.741	1.62	1.932	2.12	-0.748	2.12	-0.977
1.601	-0.961	2.306	0.173	-1.53	-2.292	1.402	-1.33	1.015	0.058	1.031	-0.738
-0.513	-0.39	-0.223	-0.14	-1.05	1.11	-0.626	1.36	-1.468	0.36	-1.751	0.86
-0.516	0.14	-0.43	0.437	-3.758	-1.596	-1.394	-0.716	-0.665	-2.64	-1.529	-0.492
-0.607	0.05	-0.114	0.193	-0.477	3.62	-0.024	3.62	-0.72	-1.937	-0.795	1.994
-1.159	-1.98	-1.095	-0.828	-2.407	-0.015	0.249	-4.38	-0.701	-4.424	-1.552	-1.641
-1.653	-2.009	-1.072	-1.634	-3.236	-3.171	-1.891	0.436	-0.756	-2.782	-2.15	-1.898
-0.092	1.304	0.085	-1.04	1.431	-1.599	0.299	-1.149	0.145	-1.862	-2.306	0.133
0.183	-0.138	0.354	-0.969	3.394	-3.183	1.545	-0.711	0.514	-2.83	-0.596	-0.21
-0.269	0.33	-0.286	-0.736	-0.172	-2.038	-0.346	0.632	0.174	-3.121	-2.122	-2.754
0.074	-0.028	0.739	-0.073	0.646	0.217	-0.981	-3.141	0.215	-0.476	0.071	-2.905
1.36	0.86	1.36	0.36	2.36	3.36	2.36	2.86	3.11	1.86	1.36	4.11
0.119	0.743	0.321	1.05	-0.259	0.049	-0.575	-0.48	-0.257	-1.555	-1.607	-0.066
0.12	0.449	1.419	-0.016	1.12	0.95	1.62	0.178	1.619	-1.7	1.12	-0.642
0.818	-0.031	1.064	-0.016	0.639	1.023	-0.145	0.486	0.22	-1.241	-1.621	-0.333
0.123	0.544	0.212	0.422	0.146	-1.844	0.046	2.9	-1.134	-2.599	-1.859	0.922
0.789	-1.443	0.565	-0.627	-0.298	0.03	0.668	0.246	-0.725	-1.824	-1.436	0.136
1.12	-1.633	0.62	-0.573	1.62	-1.621	1.62	-2.56	0.62	-1.301	1.12	-3.334
0.173	-1.989	0.323	-0.503	-0.673	-1.245	-0.347	-0.079	-1.304	0.426	0.561	0.305
0.62	-0.828	0.62	0.346	1.62	-0.445	2.12	-1.429	1.12	-0.052	1.62	-0.572
-0.39	0.12	0.11	0.12	1.61	1.12	1.86	1.62	0.86	1.62	1.61	1.12
0.442	-0.335	-0.254	0.705	-2.778	-0.32	-0.449	-0.839	-0.846	0.275	-1.198	0.586
0.081	0.228	-0.953	0.772	-2.16	0.192	-0.961	0.938	-1.928	0.296	-0.861	0.579
-0.14	1.547	0.11	1.369	0.11	1.12	0.61	1.12	1.61	0.728	0.86	1.265
-0.505	0.451	-0.604	1.308	-1.427	-0.273	-1.705	-0.193	-1.386	-0.27	-1.097	0.21
-0.52	1.12	-0.348	1.12	-0.089	1.62	0.159	2.12	3.066	1.62	-2.528	2.62
-0.64	0.62	-0.14	0.62	1.36	1.12	0.86	1.62	0.61	0.62	0.61	1.12
-1.268	-0.14	-1.125	0.36	1.336	1.36	-1.565	0.86	1.822	0.86	-2.101	1.11
0.088	-0.129	-0.377	0.983	1.14	0.347	-3.567	-1.406	0.196	0.632	-1.114	-0.271
-0.033	0.62	-0.199	1.12	-5.92	1.12	-3.674	1.12	-0.291	1.12	0.8	1.12
-0.512	-0.39	-0.651	0.11	0.024	2.61	-2.349	1.11	-0.62	1.61	1.736	-0.14
-0.064	0.313	-0.178	0.696	-1.96	2.637	-1.931	-0.936	-2	0.518	-0.016	-1.589
0.845	-0.303	0.765	-0.122	0.009	0.504	-2.091	-0.284	-0.984	1.709	-1.516	-0.733
0.62	0.136	0.62	0.359	2.12	-1.26	1.12	0.764	2.12	1.589	2.12	-1.907
-0.068	-0.427	0.086	-0.834	-0.376	2.62	-3.089	2.12	-0.226	-0.872	-1.154	-0.476
0.001	-0.434	0.542	-0.915	0.986	-0.114	-1.902	-1.426	2.681	-0.78	-0.3	-0.731

-0.14	0.11	0.61	-0.14	1.86	0.86	2.11	1.11	1.86	1.11	1.61	1.11
-0.46	-0.923	-0.189	-0.912	-1.364	-2.154	1.28	-0.088	-0.991	-1.525	-2.415	-1.001
0.62	-1.164	0.976	-0.783	1.62	-1.415	3.62	-1.215	1.12	-1.825	1.12	-2.527
-0.098	-1.532	-0.637	-1.712	-3.162	-2.402	2.498	-0.332	-1.23	-2.672	-2.226	2.672
0.12	-0.575	0.12	-0.188	0.62	-0.972	1.12	1.143	-0.38	-0.599	-0.38	2.82
1.047	1.299	0.157	0.222	-0.344	0.62	2.12	1.12	-0.826	0.555	-1.385	-1.546
-0.648	0.12	-1.065	0.62	2.879	1.12	-1.054	2.12	-2.686	0.62	-2.782	1.12
0.11	0.239	-0.14	0.861	0.86	3.753	1.11	-0.514	0.61	-1.035	0.61	0.382
0.867	0.62	1.087	1.12	1.458	5.62	1.806	2.12	0.618	3.62	0.78	2.12
-0.761	-0.39	0.376	0.11	-3.31	1.11	-3.35	0.61	-0.488	1.61	2.639	1.86
-0.17	0.287	-0.164	0.542	-0.924	1.834	-1.559	0.274	0.397	0.809	0.532	1.363
0.12	0.154	-0.38	-0.904	0.12	1.12	0.62	1.12	1.12	-0.699	1.62	-0.649
1.169	0.12	0.889	0.12	-1.075	1.12	-0.943	0.12	0.394	0.62	0.168	1.12
0.61	1.36	0.86	1.36	1.36	2.36	1.86	2.36	2.11	1.86	2.11	2.86
1.348	-0.171	1.166	-1.4	-0.482	-1.938	-0.059	-2.473	0.907	-1.863	1.565	-1.098
-0.042	0.402	-0.173	-0.276	-1.506	-2.548	-2.924	-1.497	-2.47	-1.685	-1.364	0.095
-1.194	1.12	-1.49	0.12	-2.884	1.62	-3.046	2.12	-2.871	1.62	-2.821	1.62
-0.704	-0.88	-1.084	-0.38	-3.071	-1.653	-2.807	-0.679	-1.822	-0.634	-0.483	1.12
-0.504	1.11	-0.599	0.86	-2.568	2.86	-1.394	2.61	-0.63	2.11	-0.608	2.36
1.31	-1.265	1.154	-0.387	1.62	-3.096	1.12	-2.984	-0.804	-2.708	-1.706	-1.352
0.153	-0.9	0.356	0.649	-2.109	2.502	-2.115	0.324	-0.843	-0.155	-0.939	-0.131
-0.267	1.583	-0.183	0.266	0.11	-2.076	-3.325	1.761	-0.755	2.717	-1.979	-0.148
-0.88	-0.853	0.12	-0.793	0.62	1.26	0.62	1.764	0.12	1.685	-0.38	-2.232
0.62	-0.15	1.429	-0.21	1.237	2.268	-3.317	-0.925	1.205	0.131	0.096	1.804
0.36	-0.48	0.61	-0.698	2.36	-6.099	1.86	0.123	0.86	-1.226	1.61	-4.42
0.017	0.328	0.381	-0.373	0.424	-3.507	-0.333	-2.595	0.101	-1.889	-0.965	0.23
-0.169	0.11	-0.293	-0.14	-0.474	2.11	-2.221	2.36	0.969	1.86	0.348	1.86
-0.021	0.845	-0.169	0.87	-1.87	2.735	-3.657	1.947	-3.328	2.372	-0.836	2.78
-1.152	0.966	-1.98	1.186	-1.252	1.386	-1.029	0.714	-6.614	1.659	0.729	-4.126
-0.884	0.676	-1.848	0.571	-1.18	2.12	-1.172	2.12	-2.898	0.664	-3.346	1.62
-0.38	0.228	0.12	-0.018	0.12	0.414	0.62	3.565	1.62	0.201	1.62	-5.018
0.923	-1.63	0.976	-1.893	-4.017	0.178	-3.471	1.869	-4.543	-1.311	1.883	2.189
10-1-1	10-2-1	10-1-2	10-2-2	11-1-1	11-1-2	11-2-1	11-2-2	12-1-1	12-1-2	12-2-1	12-2-2
0.25	-0.5	0.75	-0.5	1.5	0.25	0.75	0.25	0.75	0	0.5	0
0.025	-0.783	-0.02	1.209	0.415	1.702	0.441	1.478	-0.001	-0.369	0.128	-0.508
-0.069	-0.785	-0.118	-1.926	-1.229	-0.466	-0.603	-0.581	-1.548	-1.571	-1.847	-2.244
1.1	0.85	0.85	1.1	1.1	0.6	1.6	0.85	0.86	0.86	0.36	0.86
1.344	0.82	1.075	0.315	0.283	0.407	0.382	0.227	0.079	0.162	-0.381	-0.18
-0.523	0	0.837	-1	-0.562	-0.5	-0.485	-1	-2.292	0.12	-1.894	0.12
-0.4	0.3	-0.15	-0.225	0.1	-0.117	-0.15	0.057	-0.14	0.343	-0.14	0.54
-2.541	1.279	-1.808	-0.767	-0.963	0.038	-1.712	0.85	-0.702	-0.962	-0.662	-1.1

0	-1.263	0	-1.938	0	-1.148	0	-0.676	0.62	-1.11	0.62	-1.364
-1.444	0.063	-1.082	0.613	-0.77	0.138	-1.394	1.122	0.111	0.025	-0.816	0.036
0.35	-2.105	0.299	-1.941	-0.149	-1.903	0.262	-1.121	-0.32	-0.814	-0.002	-1.329
0.417	0.2	0.417	-0.395	-0.197	0.274	0.292	-0.548	-0.746	-0.479	-0.829	-1.385
0.1	-0.459	-0.15	-0.229	-0.15	-0.27	-0.15	-0.356	0.36	0.428	-0.14	-0.296
0.404	0.353	0.597	0.488	0.178	0.006	0.203	-1.161	-1.221	-0.918	-2.622	-2.24
0.616	-0.408	0.556	0.327	0.3	-0.1	0.531	-0.075	0.068	0.212	-0.106	-0.965
0.6	2.6	0.85	2.6	-0.15	2.6	0.6	1.85	0.11	1.36	0.11	1.36
1.213	0.557	1.868	0.974	1.149	0.658	1.05	0.593	0.399	-0.606	-0.257	-0.945
1	-0.579	0	-0.451	0.5	-0.098	0.5	-0.851	0.62	-0.066	0.62	-1.473
-0.757	0.1	-0.712	-0.9	-0.215	-0.4	-0.34	-0.9	-0.028	0.11	-0.181	-0.14
0.173	0.512	0.538	1.117	0.923	0.582	0.044	0.782	-0.018	0.025	-0.748	0.234
0	0.318	-0.5	0.271	-0.5	0.203	-0.5	0.219	0.62	-0.471	-1.38	-0.415
-1.083	2.35	-0.108	1.35	-1.396	1.35	-1.505	1.6	-0.238	1.36	-2.017	0.36
-0.5	-0.952	-0.5	-1.48	-1	-0.94	-1.5	-0.349	0.62	-0.207	0.12	-1.181
1.265	0.365	1.084	1.291	-0.309	0.93	0.479	0.563	1.044	-0.16	1.146	-1.705
0.744	0.1	1.257	0.1	-0.426	-0.15	-0.674	-0.15	-0.166	0.36	-0.158	0.11
1.767	-0.602	1.067	0.489	0.469	-0.62	0.376	-0.327	-2.343	-0.608	-1.246	0.502
2.343	1.5	2.837	1	1.092	1.5	2.477	1.5	-0.106	2.12	-0.324	1.62
0.945	-2.038	0.48	-1.11	3.132	-1.844	0.513	-2.556	-1.423	-1.19	-1.249	-2.344
-1.545	0.507	-0.612	0.536	-0.584	-0.3	-1.409	-0.619	-1.066	0.399	-1.101	-0.486
-1.016	1.752	-1.02	0.286	-0.193	-0.014	-0.384	0.831	-1.571	-0.984	-2.067	2.068
0.42	-1.701	0.667	1.267	-0.489	0.333	0.614	-0.769	-1.836	-0.981	-0.119	-0.271
-0.171	-0.312	-0.95	0.328	-0.649	-0.745	-0.446	-1.165	-3.565	-1.093	-2.378	-0.765
-0.589	0.421	-0.994	-0.23	0.009	1.389	-0.23	1.469	0.153	-0.44	0.228	2.103
0.6	1.85	0.35	2.1	0.35	2.6	0.6	2.6	1.61	1.36	1.11	1.36
-0.669	0.963	-0.706	0.819	-1.241	1	-1.855	0.62	0.019	0.506	-0.012	0.699
0	0.993	0	0.308	0	0.574	0	1.383	-0.88	0.141	-0.88	0.439
-1.743	-0.981	-1.7	-1.094	-1.801	-0.761	-2.228	-0.814	-2.304	-0.257	-2.242	-0.265
-2.613	-0.627	-2.606	-2.223	-2.087	-0.273	-4.01	-1.166	-1.288	0.826	-1.051	-0.117
-2.034	-0.26	-2.338	-0.339	-1.914	-0.251	-1.196	-0.836	0.912	-0.73	0.945	-1.483
-1.5	-0.644	-1.5	-1.549	-1	-1.232	0	-0.271	0.62	-1.377	0.62	-2.936
-0.809	-1.376	-0.806	-0.839	-0.747	-0.41	-0.476	-0.22	0.316	-0.024	0.147	-2.366
0	-0.764	0	-0.204	0	-0.189	0	0.076	0.62	-1.167	0.62	3.024
0.35	0	0.6	0	0.6	-0.5	0.1	0	0.61	-0.38	0.36	0.12
-0.606	-0.998	-0.995	-0.256	-0.611	-0.669	0.344	0.351	0.787	-1.3	-1.108	-0.339
-0.217	2.56	-0.85	2.576	-1.076	2.67	-0.491	2.379	-0.799	1.226	-1.206	0.943
-0.4	1	-0.15	0.5	0.35	1	1.6	1	-0.14	0.12	-0.14	-0.88
1.178	0.695	1.112	1.098	1.994	0.577	1.773	0.931	-0.497	0.035	0.065	-0.187
-0.727	1.5	-0.534	2	-0.156	1	0.072	1.5	-2.364	1.62	-0.721	1.12
-0.15	0.326	0.1	1.663	-0.65	1.759	-0.15	1.787	-1.39	-1.274	0.11	-0.273

-0.295	-0.15	-0.515	0.35	0.076	0.85	0.203	0.35	-1.443	-0.14	-1.321	0.36
-0.172	0.976	-1.116	1.081	-0.381	1.014	-0.873	1.051	-0.217	-0.185	0.304	-0.181
-0.727	0.5	0.121	1	-0.65	1.5	-0.082	1	-2.565	0.62	3.282	0.62
-0.172	0.35	0.855	0.6	0.524	0.6	0.952	0.35	-1.606	0.11	3.766	-0.14
1.048	0.585	1.365	0.56	0.551	1.169	2.078	0.779	-2.242	0.367	0.786	-0.612
1.048	2.439	3.094	0.81	1.085	1.176	0.777	2.192	-0.867	-0.351	3.749	-0.098
1	2.255	2.5	2.031	2	2.233	0.5	1.374	-0.38	0.748	0.12	-0.283
-0.132	1	0.708	0.5	1.202	0.5	0.938	1	-0.758	1.12	-0.653	1.12
0.626	0.841	1.192	0.773	3.025	1.566	2.013	0.207	-0.486	-0.406	-0.65	-0.628
0.6	2.1	0.35	1.35	0.35	1.85	0.35	0.1	0.86	0.36	-0.14	0.11
0.57	0.225	0.002	0.657	0.171	0.486	-0.244	0.356	-0.6	-0.819	-2.407	-0.351
0	-0.515	0.5	0.399	0	0.027	0	-0.318	0.62	-0.639	0.12	-0.164
-0.143	-1.627	-0.822	-0.799	-0.282	-1.386	-0.15	-1.488	-1.318	-2.128	-1.03	-1.768
-1	0.007	-1.5	0.332	-1	-0.108	-1	-0.351	-0.88	-0.003	0.62	-0.177
0.59	1	0.272	2	0.505	0	0.16	0.5	-0.574	-0.38	-0.061	0.12
0.297	-0.706	1.53	0.417	0.587	0.342	1.292	0.435	-1.104	-0.601	-1.406	0.354
0.35	0.064	0.35	0.168	0.6	0.964	0.35	0.401	-0.89	-3.061	-0.14	-0.987
2.007	0.5	1.991	0	1.379	0	1.111	0.5	1.587	0.62	1.528	1.12
0.896	-0.4	-1.044	0.1	0.191	0.35	-0.564	0.6	-2.446	-0.39	-0.156	0.11
1.456	0.253	0.558	0.682	0.27	0.413	0.158	0.329	-0.409	0.316	-0.648	0.445
0.5	1	0	1.5	0	1	0	0.5	-0.38	1.12	-0.38	-0.38
-0.341	0.43	-0.821	1.261	0.258	0.304	0.236	0.374	-0.338	0.239	0.092	0.244
1.1	2.85	1.35	1.6	0.85	2.35	0.6	2.35	0.36	1.11	0.86	0.86
1.262	0.967	1.277	0.406	0.966	0.627	0.935	0.535	1.296	-0.498	1.413	-0.629
0.105	1.105	-0.307	0.502	0.235	1.242	0.382	1.538	0.109	-0.625	-0.788	1.349
-1.575	0	-1.511	0	-1.794	0	-1.741	-1	-1.685	1.12	-1.865	1.62
-3.096	1.127	-2.95	0.069	-2.565	0.291	-2.378	0.842	-3.554	-1.946	-3.242	-0.823
-4.199	1.85	-4.192	0.85	-0.372	0.85	-3.694	1.35	-1.946	0.61	-2.179	1.36
-0.5	-1.025	-1	-1.162	0	0.351	0	0.15	-0.38	-1.716	-0.38	-0.177
-3.436	0.276	-3.258	0.109	-1.323	0.223	-1.735	0.169	-0.583	-0.274	-0.335	-0.037
-2.998	-0.271	-2.918	-0.758	-1.268	0.345	-3.648	0.28	-4.303	-0.237	-3.748	0.493
0	-1.176	0	-1.114	-0.5	-1.701	-1.5	-2.022	-1.38	-1.516	-0.38	-1.604
-0.749	0.418	-0.774	-0.552	0.078	-0.841	-1.196	-0.224	-1.749	-0.863	-1.25	-0.891
0.35	-0.085	1.35	-0.48	0.35	-1.094	0.35	-0.705	0.61	-1.188	0.36	-0.491
0.361	-1.391	-0.123	-0.75	0.311	-1.428	0.406	-1.23	-0.746	0.013	-0.308	0.213
-0.195	-0.9	0.039	0.35	0.122	0.35	-0.635	0.1	0.144	0.11	1.255	0.11
-1.231	-1.407	-2.294	0.176	-0.517	-0.121	-2	-0.249	-1.525	0.161	2.382	0.358
-3.653	0.295	-0.969	-0.283	-0.524	-0.293	-1.419	-0.29	-0.199	0.162	0.531	1.075
-2.549	0.5	-2.588	-1	-3.698	-0.5	-3.243	0	-2.678	-0.38	-0.498	0.62
-1.5	1.02	-1.5	0.384	-0.5	0.351	-2	0.595	-0.88	0.294	1.12	1.1
-3.402	1.75	-2.821	2.25	-1.449	0.259	-2.964	2.03	-0.106	-0.906	-1.202	-0.725

13-1-1	13-2-1	13-1-2	13-2-2	14-1-1	14-1-2	14-2-1	14-2-2	15-1-1	15-1-2	15-2-1	15-2-2
0.25	-0.25	0.5	-0.25	3.25	0.75	3.25	2	2.5	1	2.5	1.25
0.524	0.06	-0.603	0.06	-2.438	-3.192	-2.171	-3.079	-0.342	0.048	-0.917	0.06
-0.997	-1.292	-0.995	-1.232	-3.912	-1.959	-0.002	-1.307	-1.898	-1.983	-1.789	-1.878
-0.14	0.86	-0.14	0.86	3.86	2.11	2.36	2.36	2.36	1.86	1.86	2.36
-0.374	0.621	-0.622	-0.139	0.974	0.838	0.712	0.546	0.787	0.511	-0.688	0.243
-1.098	0.12	-1.549	-0.38	-0.012	1.62	-0.016	1.12	0.051	1.12	-1.341	1.12
-0.39	0.47	-0.39	-0.357	1.61	-0.56	2.36	-0.637	0.86	-0.548	0.86	-0.49
-0.562	-0.043	-0.538	-2.207	-1.571	-1.372	3.162	-0.375	2.926	-1.628	-0.72	-1.749
0.62	-1.447	0.62	-2.664	1.62	-2.553	3.12	-0.984	3.12	-2.013	1.62	-2.927
0.547	0.475	0.746	-0.198	-1.597	1.183	-0.511	2.037	0.005	0.343	-0.97	-0.384
1.021	-0.947	-0.568	-2.136	-0.285	-0.74	0.339	-0.679	0.191	-1.536	-0.883	-3.538
-0.239	-0.013	0.265	-1.198	-0.103	2.714	-2.187	-1.21	-0.191	1.242	-1.365	-2.06
0.61	0.341	-0.14	-0.786	1.36	-1.041	2.61	-2.544	2.61	1.557	1.11	-1.8
-0.634	-0.186	-2.312	-1.711	-1.608	-1.37	-0.801	-0.652	-1.757	-0.005	-3.224	-3.212
0.336	0.709	-0.394	-1.158	-1.926	0.669	0.104	1.006	0.39	1.023	0.374	-1.029
-0.14	1.86	0.11	0.86	1.61	4.86	1.36	2.86	1.11	2.86	1.61	2.36
0.288	0.385	0.473	-1.027	0.275	-0.816	-0.4	-1.365	-0.443	-0.981	0.567	-0.929
1.12	-0.49	0.12	-1.36	1.62	3.905	1.12	-0.278	1.12	-1.205	1.62	-2.246
0.14	-0.89	-0.741	-1.14	-1.476	1.61	-2.089	1.86	-1.002	0.86	0.087	1.36
-0.318	0.251	-0.039	0.002	0.74	-0.868	-1.985	0.194	-2.394	-0.638	-0.48	0.412
0.12	-0.017	0.12	-0.147	1.12	-1.44	1.12	-2.221	0.62	-1.711	1.12	-0.376
0.473	0.36	-0.673	0.36	-1.567	0.86	-2.466	0.86	0.848	1.11	-0.312	0.86
0.12	0.526	0.118	-0.292	1.12	-0.389	1.62	-1.608	2.12	-1.383	1.12	-1.33
1.379	0.08	1.726	0.356	0.326	-2.208	1.125	-2.314	1.359	-1.24	0.715	-1.902
0.029	-0.39	-0.224	-0.64	-2.274	1.11	-0.805	1.11	-0.576	0.86	-2.189	0.86
-0.287	1.007	-0.676	-0.009	-2.552	-1.792	-1.729	-1.394	0.059	-1.246	-1.798	-1.233
-0.551	1.12	0.21	1.12	-1.231	4.12	0.071	3.12	0.108	2.62	-0.382	2.62
-1.035	-1.12	-0.054	-1.214	-1.705	2.142	1.24	0.272	-0.166	-0.643	-2.685	-2.543
-1.658	0.271	-0.835	-2.256	-3.01	-3.987	-1.434	-0.265	-2.225	0.851	-2.813	0.446
-1.22	1.651	-1.137	-0.892	-2.421	-1.563	0.086	-1.489	-0.354	0.363	2	0.259
-0.458	-0.331	-1.008	-1.162	-2.001	-2.963	0.655	-1.589	-1.241	-3.314	2.252	-1.729
0.211	-0.903	-1.634	-1.261	-3.909	-2.164	0.339	-2.125	-2.209	-0.713	0.167	-0.689
0.11	0.296	-0.083	0.409	-1.699	-1.145	1.572	0.435	-0.287	-2.382	-1.171	-1.813
1.36	0.86	0.86	0.36	4.11	2.36	2.86	2.36	1.86	2.36	2.36	2.61
0.132	0.659	-0.566	0.293	-0.218	-0.571	-0.621	-0.53	-0.344	-0.476	1.377	-0.46
0.62	0.273	0.62	0.229	1.62	0.074	1.12	0.015	1.12	-1.345	1.12	-2.288
-0.662	-0.175	-0.45	-0.851	-2.471	3.414	-2.629	3.198	-2.007	-1.342	-2.132	-0.544
-0.036	0.462	-0.755	-0.267	0.143	-2.444	-0.121	-1.997	-1.139	-1.428	-1.453	-0.862
0.217	-0.485	-0.399	-0.827	0.642	0.43	0.345	0.029	-0.035	-2.204	-0.63	-1.349
1.12	-0.984	0.62	-0.53	1.62	-2.542	1.62	-2.635	1.12	-2.124	1.62	-2.347

0.531	-0.871	-0.184	-0.663	-0.694	-2.329	-0.597	-2.643	-0.798	-1.324	-0.476	-0.752
1.12	0.112	0.62	0.209	1.12	-2.21	2.12	-1.156	1.62	-0.922	1.12	-0.255
-0.39	-0.38	-0.14	0.62	0.61	1.12	2.86	1.62	1.86	1.12	0.86	1.12
-0.473	-1.715	0.257	-0.339	-4.15	-0.875	-2.449	-0.921	-2.782	-2.159	-2.814	-1.218
-0.548	-0.6	-1.768	0.136	-1.464	4.091	-1.046	1	-1.767	-1.534	-1.83	0.238
-0.39	-0.88	-0.64	0.62	0.86	1.12	0.61	1.12	0.61	1.12	0.61	1.12
-0.684	0.276	-1.631	0.374	-0.795	-0.073	-0.743	-0.451	-1.476	2.239	-1.497	0.39
-1.244	0.12	-1.677	1.12	0.368	1.62	-1.647	1.62	-2.056	2.62	-1.054	1.62
-0.64	-0.028	-1.14	0.829	0.86	-1.75	1.11	-2.172	0.11	-0.384	1.11	-1.637
-1.184	-0.39	-1.316	-0.14	-0.785	1.11	-1.321	1.36	-0.407	1.11	-1.203	2.36
-0.492	-0.253	-0.334	-0.6	1.015	-2.461	-2.654	2.571	-0.061	-0.21	-0.274	0.108
-0.074	0.12	-1.858	0.12	-2.18	2.12	1.357	1.62	1.7	1.12	-1.304	1.62
-0.505	0.11	-1.75	0.11	2.319	1.36	2.938	4.11	1.089	1.86	-0.878	1.36
-0.194	-0.408	-1.49	0.359	-1.404	0.802	0.23	-2.234	-2.214	0.17	0.044	-0.34
0.83	-0.13	0.022	-0.261	1.046	-0.099	3.662	-2.94	-0.866	0.039	2.744	0.053
0.62	0.316	0.12	0.35	3.12	3.906	2.12	-1.138	2.12	-0.181	2.12	-0.448
-1.241	0.62	-1.219	1.62	-0.059	2.12	1.471	2.12	-0.964	1.62	-1.066	1.62
-1.22	-1.081	-0.239	0.835	1.106	-0.493	-5.738	0.698	1.418	-1.967	-0.932	-0.059
-0.39	0.36	1.11	0.61	1.86	1.61	2.11	1.11	2.11	1.11	1.61	0.86
-0.134	0.321	-0.331	0.736	-2.108	-0.598	-0.862	-1.936	-1.217	-0.526	-1.059	-0.999
0.62	-0.16	0.12	0.147	1.12	0.305	2.12	-1.871	1.62	-1.084	1.62	-1.461
-0.433	-1.418	-1.279	-0.29	-3.898	1.705	-1.981	-3.493	-1.588	2.025	-1.16	-2.959
0.12	0.092	0.12	0.133	0.62	0.692	-0.38	3.651	0.12	0.962	0.12	-0.419
0.115	-0.88	0.508	0.62	0.793	1.12	-1.923	1.12	-1.039	1.12	-2.943	1.12
-1.415	-0.497	-0.25	-0.326	0.445	-0.622	-2.42	2.049	-1.575	-0.603	-0.037	-1.308
0.11	-0.391	0.11	0.111	1.11	-0.639	0.61	0.855	0.86	-0.572	1.61	3.311
1.759	0.62	0.389	0.62	1.895	2.12	-0.103	4.62	0.147	2.62	1.555	3.12
0.458	0.11	-0.355	-0.14	-2.605	0.61	-4.672	1.36	-3.2	0.61	0.861	1.36
0.038	1.124	-1.206	0.493	-0.365	-0.189	-1.827	1.087	-1.94	-0.017	0.882	0.944
0.12	0.12	-0.88	0.62	1.12	1.12	0.62	1.62	0.62	1.12	1.12	1.62
0.769	-0.123	-0.577	0.761	-0.088	-2.882	-1.076	-1.04	-0.929	-1.697	0.303	-1.737
1.11	1.61	0.36	1.36	1.86	2.36	2.36	2.11	1.61	2.11	1.36	2.11
1.196	-0.612	0.843	0.61	0.166	-1.509	1.098	-1.085	0.754	-1.688	0.668	-1.739
-0.123	-0.363	-1.033	1.692	-2.03	2.332	0.117	-1.23	-2.898	-2.373	-3.286	-0.123
-1.459	0.62	-1.896	1.12	-3.462	2.12	-1.567	2.12	-2.665	1.62	-2.966	1.62
-1.821	-1.594	-2.416	-0.6	-2.825	-0.828	-1.953	-2.164	-2.656	-2.949	-1.774	-2.582
-0.648	1.36	-1.381	1.11	-2.07	2.36	1.724	2.86	-1.063	2.11	-1.264	2.36
0.12	-0.675	-0.88	-0.43	0.62	-2.87	4.62	-2.286	1.62	-1.642	1.12	-1.731
0.724	-0.167	-0.81	0.023	-1.135	-1.398	1.247	1.014	-1.181	2.52	-1.795	-0.932
-0.125	-0.87	-1.712	1.6	-3.665	-2.807	-0.225	0.05	-2.66	0.042	-3.089	2.28
0.12	-2.094	-0.38	-0.36	0.12	-1.542	1.12	1.53	-0.38	-1.412	0.12	1.253

1.16	-0.508	0.073	0.107	-2.192	-2.051	2.087	-0.99	-1.134	2.93	-1.911	-0.046
0.36	-0.751	0.61	-0.52	2.11	-2.389	2.11	0.01	1.61	0.527	1.61	0.484
0.116	-0.523	0.303	-0.216	-0.648	-3.252	1.4	-2.988	-0.558	-1.67	-0.617	-0.144
0.211	-0.39	0.272	-0.89	-2.518	1.61	-6.794	1.86	0.22	2.11	-0.674	1.86
-0.713	0.033	-0.138	0.51	3.012	-0.241	-3.379	0.782	-0.986	3.24	-2.347	0.707
-1.834	0.011	-2.072	0.968	2.108	0.537	-8.663	1.497	0.254	2.318	-0.562	0.496
-0.732	0.12	-2.255	0.62	0.155	2.12	-4.264	2.12	-0.44	2.12	-2.531	2.12
0.12	-0.066	-1.38	0.796	2.12	-0.233	3.62	0.82	2.12	0.435	0.12	0.978
0.382	-0.826	-0.087	-0.586	1.463	0.5	1.659	0.425	-3.769	0.83	-2.893	-0.543

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14. ABSTRACT

The Airborne Precision Spacing (APS) team at the NASA Langley Research Center (LaRC) has been developing a concept of operations to extend the current APS concept to support dependent approaches to parallel or converging runways along with the required pilot and controller procedures and pilot interfaces. A staggered operations capability for the Airborne Spacing for Terminal Arrival Routes (ASTAR) tool was developed and designated as ASTAR10. ASTAR10 has reached a sufficient level of maturity to be validated and tested through a fast-time simulation. The purpose of the experiment was to identify and resolve any remaining issues in the ASTAR10 algorithm, as well as put the concept of operations through a practical test.

15. SUBJECT TERMS

Airborne spacing; Dependent runways; Interval management; Parallel runways

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