MTR110426R1

MITRE TECHNICAL REPORT

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Sponsor: The Federal Aviation Administration
Dept. No.: F084
Project No.: 0216HT02-31
Outcome No.: 02
PBWP Reference: 2-6.I.1, ADS-B Enabled Applications: Concept Refinement, Standards, Engineering, and Risk Reduction Activities

Approved for Public Release; Distribution Unlimited. Case Number 16-1219.

Executive Summary

Interval Management-Spacing (IM-S) is a concept enabled by Automatic Dependent Surveillance-Broadcast (ADS-B) technology. It consists of ground and flight deck-based capabilities and procedures designed to enable aircraft to achieve and maintain spacing relative to each other. IM-S delegates the spacing task to the flight deck and enables flight crews to follow speed guidance generated by avionics to achieve and/or maintain spacing relative to a Target Aircraft. IM-S increases throughput in capacity constrained airspace by spacing aircraft closer together more consistently than is otherwise possible.

Over three nights in 2010, a field test of IM-S during Arrival and Approach (IM-S AA) was performed with UPS Boeing 767 aircraft during Optimized Profile Descents (OPDs) into Louisville International-Standiford Field (SDF). It was the first known test of an implementation of IM-S AA through OPDs with certified equipment and operationally approved procedures during revenue flights. The tested concept was an initial implementation of IM-S AA and therefore included some characteristics not expected in a more robust implementation (e.g., the UPS Global Operations Center initiating the operation instead of Air Traffic Control [ATC]). The test was sponsored by the Federal Aviation Administration (FAA) Surveillance and Broadcast Services Program Office and UPS, and data collection was planned and coordinated by a team of organizations such as the FAA, The MITRE Corporation, the National Aeronautics and Space Administration (NASA), UPS, and Aviation Communication & Surveillance Systems (ACSS).

The 2010 IM-S AA Field Test built from previous experience in IM simulations (e.g., NASA, MITRE, EUROCONTROL) and initial field operations (i.e., UPS, ACSS) and was intended to demonstrate the viability of the concept for maturing and validating relevant portions of IM-S documentation. The test also provided field validation of the operational application, as well as data to support standards development and benefits analysis. As a culmination of years of development activities and preliminary field flights, the specific research objectives were to examine the IM-S AA concept, phraseology, ATC and flight crew procedures and tools, as well as algorithm outputs and interval delivery at significant points.

Research observers and operational experts were stationed in ATC facilities and on the IM-S AA aircraft flight decks. The researchers collected data through observations of the pilots and controllers. Additionally, equipment on-board the IM Aircraft recorded aircraft state data. Some of the metrics used to inform the research objectives included spacing values and tolerances achievable in the field, crew and controller actions during actual operations, and user acceptability, performance, and human factors.

No major conceptual, human factors, or operational issues were identified by ATC or pilots for the implementation of IM-S AA as implemented by UPS. Most test participants reported being comfortable with the operation, procedures, and workload. Once IM-S AA had begun, no ATC interventions were made with any of the IM-S AA aircraft across all three test events. No major issues were noted with phraseology and communications, although there appeared to be some ambiguity about when flight crews need to inform ATC that they are terminating the IM-S operation.

Across the flights, the IM Speed changed on a per flight basis on average between every seven and every 36 minutes during the IM-S AA Achieve Phase. In the Maintain Phase the IM Speed changed on a per flight basis on average between every 100 and every 180 seconds. Most crews reported that they were comfortable with this rate. During the operation, pilots also changed aircraft speed without regard to the IM Speed, which was expected. One of the main reasons was when crews reduced speed to comply with the first procedural speed crossing restriction. Another common reason was when they stepped down to their final approach speed independent of the IM Speeds.

Flight crews showed mostly high conformance following the IM Speeds in the Achieve Phase and all but one aircraft with available SafeRoute data achieved the spacing goal at the achieve-by point within +/- 6 seconds. In the Maintain Phase, six of the eight flights with available SafeRoute data showed mostly high-to-medium IM Speed conformance and were able to maintain the spacing goal within +/- 10 seconds throughout the phase. Their final spacings, i.e., the observed time spacing when their Target Aircraft touched down, were all within +/- 8 seconds of the spacing goal. Two flights exhibited especially low IM Speed conformance during the latter part of the Maintain Phase and exhibited final spacings 46 and 49 seconds outside of the spacing goal.

The field evaluation identified several potential issues for further concept development. These included interactions between OPD energy management (such as speed constraints) and IM Speed conformance (such as accelerations during descent). Consideration should be given to the appropriate IM-S AA initiation location, given that conformance to the IM Speeds appears to have less impact on final spacing performance the farther away it is from the point of measurement. In addition, crews may need information to help them to determine whether or not they are conforming to an IM clearance beyond just how closely they comply with the IM Speeds. Clear communications procedures with ATC regarding on-going conduct and termination should be established and trained.

The results from this field evaluation helped validate past fast-time and HITL simulation results that suggest overall concept acceptability and feasibility. The results also provide performance data that can be used as parameters for future modeling and simulation research. The results should also be helpful for display and other system requirements as further FAA flight test and avionics standards are developed.

Acknowledgements

The authors first wish to thank UPS for supporting the test and allowing data collection on board the aircraft and at their Global Operations Center. In particular, thanks to Christian Kast, Todd Montgomery, Ken Kirk, and Jeff Firth of UPS for managing aircraft and observer logistics. The authors also thank the Federal Aviation Administration (FAA) Surveillance and Broadcast Services (SBS) Program Office for sponsoring the data collection activity. Thanks also to Vern Battiste of NASA Ames / San Jose State University for helping to plan the data collection effort. Thanks to Chuck Manberg and Gabriel Brewer of Aviation Communication & Surveillance Systems (ACSS) for help with SafeRoute data reduction and interpretation.

Thanks to all the observers for collecting the data. Also thanks to the Kansas City and Indianapolis Air Route Traffic Control Centers (ARTCCs) as well as the Louisville Terminal Radar Approach Control (TRACON) for supporting the event. Thanks to all of the air traffic controllers and UPS pilots who participated in the operation and patiently filled out questionnaires and answered observer questions. Thanks to Wes Stoops of Regulus Group for coordinating the Air Traffic Control (ATC) facility logistics.

Thanks to Ian Levitt of the FAA and Lesley Weitz of MITRE for helping to develop the test objective matrices. Thanks to Brock Lascara of MITRE and Dr. Fidel Parraga for assistance with data reduction and analysis. Thanks also to all the individuals and organizations that supported the data collection and to Janet Harvey of MITRE and Andrea Hunt for helping to prepare this document. The list of individuals that participated in the test planning, data collection, and data analysis is provided at the end of this document in Appendix E. Organizational contributions are also credited as appropriate with specific results.

Acronyms and Abbreviations

Acronym	Definition
A-IM	Advanced Interval Management
AA&C	Arrival, Approach, and Cruise
ABESS	Airline Based En route Sequencing and Spacing
A/C	Aircraft
A/P	Autopilot
A/T	Autothrottle
ACARS	Aircraft Communications Addressing and Reporting System
ACSS	Aviation Communication & Surveillance Systems
ADC	Air Data Computer
ADS-B	Automatic Dependent Surveillance - Broadcast
AGD	ADS-B Guidance Display
AGL	Above Ground Level
AMAN	Arrival Manager
AOC	Airline Operations Center
ARC	Aviation Rulemaking Committee
ARTCC	Air Route Traffic Control Center
ASG	Assigned Spacing Goal
ATC	Air Traffic Control
B	Boeing
CAS	Calibrated Airspeed
CAVS	Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation
CDA	Continuous Descent Arrival
CDTI	Cockpit Display of Traffic Information
CMD SPD	Commanded Speed / Interval Management (IM) Speed
CONOPS	Concept of Operations
CPDLC	Controller Pilot Data Link Communications
CPT	Captain
EFB	Electronic Flight Bag
ETMA	Extended Terminal Control Area
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FAS	Final Approach Speed
FDMS	Flight Deck-Based Merging and Spacing
FIM	Flight deck-based Interval Management
FL	Flight Level
FMS	Flight Management System
FO	First Officer
FOQA	Flight Operations Quality Assurance

Acronym	**Definition**
ft	Feet
GIM	Ground-based Interval Management
GNSS	Global Navigation Satellite System
GOC	Global Operations Center
HITL	Human-in-the-loop
IAF	Initial Approach Fix
IAS	Indicated Air Speed
IM	Interval Management
IM-S	Interval Management – Spacing
IM-S AA	Interval Management – Spacing during Arrival and Approach
IM SPD	Interval Management Speed
INCR	Incremental
IOC	Initial Operational Capability
ITT	In-Trail Time
JHU APL	Johns Hopkins University Applied Physics Laboratory
KATL	Hartsfield – Jackson Atlanta International Airport
KIAS	Indicated Airspeed (knots)
kt	Knot
L	Left
LAX	Los Angeles International Airport
LDPU	Link and Display Processor Unit
LGB	Long Beach Airport (Daugherty Field)
LNAV	Lateral Navigation
LOA	Letter of Agreement
M	Mach
M&S	Merging and Spacing
M_{MO}	Maximum Operating Speed - Mach
MCP	Mode Control Panel
MIN	Minutes
MIT	Miles-In-Trail
MOPS	Minimum Operational Performance Standards
NASA	National Aeronautics and Space Administration
NM	Nautical Mile
ONT	Ontario International Airport
OPA	Operational Performance Assessment
OPD	Optimized Profile Descent
ORD	Chicago O-Hare International Airport
OSED	Operational Services and Environment Definition
PF	Pilot Flying
PHX	Phoenix Sky Harbor International Airport

Acronym	Definition
PM	Pilot Monitoring
PXV	Pocket City (Merge Fix and Achieve-by Point)
R	Right
RFG	Requirements Focus Group
RNAV	Area Navigation
RTA	Required Time of Arrival
RTCA	RTCA
S&M	Sequencing and Merging
SA	Situation Awareness
SAN	San Diego International Airport
SBS	Surveillance and Broadcast Services
SC	Special Committee
SCR	Speed Crossing Restriction
SDF	Standiford Field, Louisville, KY
SDSS	Surface Decision Support System
SEC	Seconds
SEL	Selected Speed
SG	Subgroup
SGT	Small Group Tryout
SPR	Safety and Performance Requirements
STC	Supplemental Type Certificate
TCAS	Traffic alert and Collision Avoidance System
TGT TD	Target Aircraft Touchdown
TGT	Target (aircraft)
TMU	Traffic Management Unit
TOC	Top Of Climb
TOD	Top Of Descent
TRACON	Terminal Radar Approach Control Facility
UTC	Universal Time Coordinated
V_{MO}	Maximum Operating Speed – Knots
VNAV	Vertical Navigation
VOR	Very High Frequency (VHF) Omnidirectional Range
WG	Working Group
ZAB	Albuquerque ARTCC
ZID	Indianapolis ARTCC
ZKC	Kansas City ARTCC

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1 Introduction

Interval Management – Spacing (IM-S) is an Automatic Dependent Surveillance-Broadcast (ADS-B) In enabled suite of flight deck capabilities and procedures that enable an aircraft to manage its position to a time or distance in relation to the trajectory of another aircraft. IM-S improves inter-aircraft spacing precision and enables multiple aircraft to be spaced more consistently than using a static reference point, such as a point on the ground or clock time. The inter-aircraft spacing goal can be based on a metering schedule, applicable separation standard, miles-in-trail restriction, or any other operationally-relevant spacing objective.

IM-S improves operational efficiency through implementation of airborne speed and/or turn instructions. The closed-loop nature of IM allows for more speed adjustments per flight segment, achieving a desired spacing interval more effectively than if provided by ground automation. When IM-S capability is considered by ground scheduling automation, the time or distance interval between in-trail aircraft pairs can be reduced thus, increasing capacity without negatively impacting controller workload or task complexity. As it primarily uses speed guidance to effect trajectory changes, IM can also reduce controller vectoring of aircraft flying Optimized Profile Descents (OPDs), especially during times of high demand.

IM-S avionics capabilities and performance are defined in RTCA (2015) and EUROCAE (2015). IM-S implements an Airborne Spacing concept derived from research activities in the United States and Europe, in which “Flight crews achieve and maintain a given spacing with designated aircraft, as specified in a new instruction. Although the flight crews are given new tasks, separation provision is still the controller's responsibility and applicable separation minima are unchanged” (FAA/EUROCONTROL Cooperative Research & Development, 2001). IM-S was categorized into four areas by the ADS-B In Aviation Rulemaking Committee (ARC) (ARC, 2010), some of which overlap (Figure 1-1). IM-S during Arrival and Approach (IM-S AA) is one of the four ARC categories and is one of several IM-S scenarios allowed by RTCA (2015).

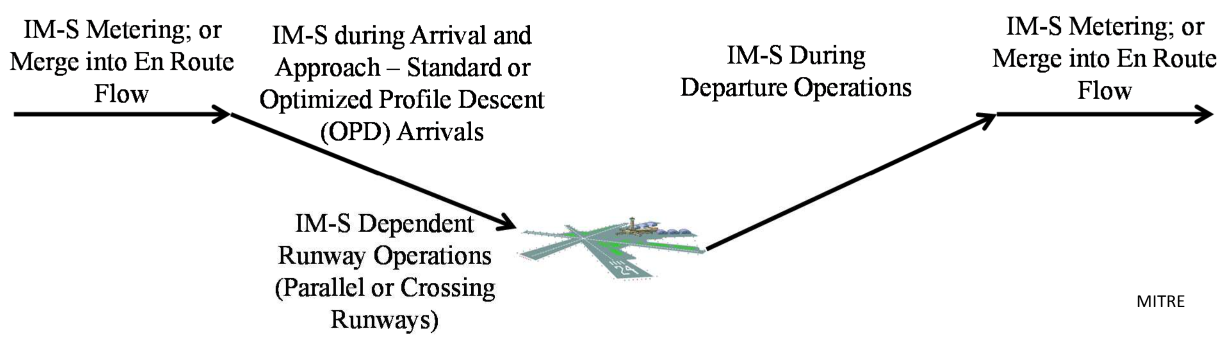


Figure 1-1. Four ADS-B In ARC Defined IM-S AA Applications

Numerous simulations have been conducted on concepts very similar to IM-S AA, but only a few limited field or flight tests have been conducted. To validate Human-In-The-Loop (HITL) and other research results, a field test of IM-S AA was performed with UPS Boeing 767 aircraft flying OPDs into Louisville International-Standiford Field (SDF) over three nights in 2010. This was the first test of IM-S AA implementation through OPDs with certified equipment and operationally approved procedures during revenue flights. It built upon previous experience in IM simulations and initial field operations and was intended to demonstrate the viability of the concept for maturing and validating relevant portions of IM-S documentation. The test also provided field validation of the operational application, as well as field data to support standards development and benefits analyses.

The tested concept was an initial implementation of IM-S AA (e.g., limited initiation support and the Global Operations Center [GOC] providing the assigned spacing goal and Target Aircraft) and therefore included some characteristics not expected in a more robust implementation. The test was sponsored by the Federal Aviation Administration's (FAA) Surveillance and Broadcast Services (SBS) Program Office and UPS, and data collection was planned and coordinated by organizations such as the FAA, The MITRE Corporation, the National Aeronautics and Space Administration (NASA), UPS, and Aviation Communication & Surveillance Systems (ACSS).

The first section of this report describes the IM-S AA concept, related research, and the UPS implementation. Section 2 describes the field test objectives and data collection methodology. Section 3 describes the test environment and Section 4 provides the results. The results are discussed in context with past literature in Section 5, and the final conclusions and recommendations are listed in Section 6.

1.1 IM-S during Arrival and Approach (IM-S AA)

Aircraft arriving at an airport typically originate from numerous departure points and traverse different routes prior to merging into an arrival stream. This convergence is often necessary for an orderly delivery to the arrival and approach and is accomplished through merging at downstream en route or terminal area waypoints. In order for the merge to be successful, aircraft on the routes to be joined must be synchronized in time and have sufficient spacing to allow for other aircraft to fit into the overall flow while maintaining, at least, the minimum required separation between aircraft.

Air Traffic Control must merge the flows and maintain the separation standards while maneuvering the aircraft to meet restrictions from downstream sectors. Flow restrictions, such as Miles-In-Trail (MIT) or metering restrictions, are often put in place to absorb delays when the downstream sector or an airport is predicted to be or is currently congested due to conditions such as weather or the volume of traffic (Kopardekar, Green, Roherty, and Aston, 2003). Flow restrictions can also be put in place to meet spacing requirements for procedures such as OPDs that require a minimum spacing between aircraft pairs prior to flying the arrival so aircraft are able to fly the arrival uninterrupted.

In the case of express package operations, the overall spacing / time between the first aircraft arrival and the last aircraft arrival is critical. The arrival time of the last aircraft is pivotal because this arrival determines when the outbound aircraft can be loaded and subsequently depart. Cargo from the arrivals must be unloaded and sorted prior to any of the aircraft departing. Therefore, it is desirable to have all aircraft arrive in an optimally-spaced set within an appropriate window of time.

If spacing cannot be achieved early on in the flight and MIT restrictions are in place, vectors are typically used to adjust in-trail spacing or to avoid conflicts since speed changes are often inadequate to sufficiently alter the spacing within the sector (Green and Grace, 1999). Instead of being able to direct an aircraft to maintain a specific in-trail spacing interval, controllers must provide specific instructions, or instruction sequences, in order to achieve their goal. This process can be workload intensive for controllers and pilots and can also increase fuel consumption and flight time.

To complement traditional flow management, an ADS-B In-enabled concept termed IM-S is being actively developed in the US and Europe. Although IM-S is broadly applicable to several flight domains, IM-S AA is specifically intended to allow flight crews, ATC, and airlines to efficiently achieve and / or maintain an Assigned Spacing Goal (ASG) between aircraft from the en route phase of flight down to the final segments of the approach. IM-S AA has both air and ground components. The ground set-up component is a set of ATC procedures and tools that help controllers manage aircraft metering operations and initiate and monitor the flight deck component. Ground tools may be required in some, but not all, cases to manage an IM operation. At the minimum, however, ATC needs to have knowledge of which aircraft are capable of performing an IM operation. The air component consists of flight crew procedures and onboard, Flight deck-based Interval Management (FIM) equipment that provides flight crews with speed guidance (termed IM Speeds) to enable them to achieve and/or maintain an ASG from a Target Aircraft.

IM-S AA procedures can vary, but a basic operation may start when a decision is made to conduct IM-S AA between a pair of aircraft. First, ATC with the support of ground automation, formulates and communicates an IM clearance to an IM equipped aircraft. IM clearance information would typically include the call sign of the Target Aircraft, the ASG, and the point at which to achieve (i.e. the achieve-by point), and then maintain, the ASG until termination. The flight crew then notifies ATC that they accept or reject the IM clearance. If they accept the IM clearance, the flight crew then enters the initiation message elements into the FIM equipment and arms the system. If the Target Aircraft is in range and other initiation criteria are satisfied, the IM operation can begin. The planned termination point can vary, but in many cases will likely be at or near the Final Approach Fix (FAF).

After set-up, the FIM equipment provides IM Speeds which enable the flight crew to achieve and/or maintain the ASG. With the presentation of each IM Speed, the flight crew ensures that the IM Speed is feasible for the aircraft configuration under current conditions. IM-S does not change any existing requirement or introduce new speed change notification procedures and IM-S AA does not preclude ATC from providing a speed or heading instruction at any time. However, ATC-initiated trajectory changes to the IM Aircraft can result in IM-S AA termination. If this were to occur, flight crews would be expected to fly speeds issued by ATC or as required by procedure.

IM Speeds can be provided until the IM Aircraft reaches approximately the FAF, at which point they are no longer displayed. The flight crew then slows to the Final Approach Speed (FAS) and configures the aircraft for a normal landing.

1.2 IM-S AA Benefits

The main objective of IM-S AA is to achieve consistent, low variance intervals between aircraft at the entry to an arrival procedure (e.g., OPD) and on final approach through the use of airborne speed and/or turn adjustments. As noted earlier, the closed-loop nature of IM allows for more speed adjustments to be made for a given flight segment to achieve the spacing goal than could be provided by a ground system. This enables aircraft pairs achieve spacing goals more consistently which is expected to result in increased capacity. For example, Boursier, L., Cloarec, D., Favennec, B., et al., (2005) found the use of Arrival Manager (AMAN) and IM-S AA together improved delivery of the intervals between aircraft both at the Initial Approach Fix (IAF) and the Final Approach Fix (FAF) over AMAN alone. Consistent delivery at the FAF with reduced variance (i.e., almost all aircraft within +/- 5 seconds) allowed for increased throughput of two more aircraft per hour over scenarios with AMAN alone. The study also found a slight reduction in maneuver instructions in the Extended Terminal Control Area (ETMA) and a drastic reduction in the terminal area.

Other studies have shown similar accurate delivery of spacing between aircraft. Grimaud, Hoffman, Rognin, and Zeghal (2003) found that more aircraft were delivered closer to the target interval for Sequencing and Merging (S&M)[1] in the extended terminal area with distance-based ASG with IM-S AA (42%) than without (17%). Additionally, fewer aircraft were delivered with too small (or too large) spacing. Therefore, they reported a more homogeneous and stable flow at the delivery point with more aircraft achieving the target spacing value under IM-S AA. Oseguera-Lohr, Lohr, Abbott, and Eischeid (2002) reported a pilot evaluation in a high fidelity simulator where the ASG was achieved within +/- 5 seconds. Lohr, Oseguera-Lohr, Abbott, Capron, and Howell (2005) conducted a flight test where the target ASG of 90 seconds was achieved with an average of 90.8 seconds with a standard deviation of 7.7 seconds. Through such delivery of aircraft, IM-S AA is expected to increase the predictability of operations. Aircraft will be delivered with a conditioned sequence and spacing on a regular basis.

IM-S AA may also have a positive impact on safety through accurate and consistent delivery of aircraft. Although Grimaud, et al. (2003) found potentially unsafe spacing delivery of aircraft with and without IM-S AA in the extended terminal area using distance-based ASG, IM-S AA did not introduce more unsafe conditions. In fact, IM-S AA actually reduced the number of unsafe or unstable handoffs. Only one unsafe transfer was seen with IM-S AA, and it occurred when the initial applicability conditions had not been adhered to by the controller. Aligne, Grimaud, Hoffman, Rognin, and Zeghal (2003) also found a number of unsafe conditions that were due mainly to inappropriate initial conditions. No separation violations were found in an examination of IM-S AA in the en route environment (Bone, Penhallegon, Stassen, Simons, and DeSenti, 2007).

[1] Sequencing and Merging (S&M) is a term used during the EUROCONTROL development of an IM-S AA concept.

In the study by Mercer, Callatin, Lee, Prevot, and Palmer (2005), controllers reported that spacing operations were safe for conditions in which they both had and did not have new spacing tools.

IM-S AA is expected to reduce the number of controller interventions. Numerous studies have shown a reduction in controller interventions for similar concepts conducted in the en route and terminal areas (e.g., Grimaud, Hoffman, Rognin, Zeghal, and Deransy, 2001; Grimaud, et al., 2003; Aligne, et al., 2003; and Mercer, et al., 2005). A study specifically examining IM-S AA in the en route environment (Bone, et al., 2007) reported a reduction in controller instructions in IM-S AA scenarios (as compared to scenarios without IM-S AA) even with spacing disruptions and the introduction of other issues. It was also found that the FIM equipment did not provide any more IM Speeds when it was managing spacing than the controller when managing spacing in a baseline condition.

Because IM-S AA is expected to reduce the number of controller interventions, less frequency congestion is also likely to occur. Grimaud, et al. (2001) found a reduced number of communications when examining IM-S AA from a controller's perspective from the en route environment to the IAF. They did not, however, find a reduction in the duration of the communications. In a flight test / demonstration, terminal controllers described a positive effect on communications with pilots (FAA, 2001). A study specifically examining IM-S AA in the en route environment (Bone, et al., 2007) reported both subjective and objective data indicating a reduction in controller-pilot communications. Controllers reported that their communications were easy and reduced with IM-S AA. Objective data revealed fewer ATC-initiated communications and less total time on the frequency during IM-S AA. A summary report of several European IM-S AA simulations (Hebraud, Martin, Leone, and Troise, 2006) included a study of Italian airspace that also found reduced communications. Previous research on similar spacing concepts (Williams and Wells, 1986; Hebraud, Hoffman, Papin, et al., 2004; Hebraud, Hoffman, Pene, et al., 2004; Melanson, 1973) reported pilot data that suggested reduced communications with ATC as compared to current operations.

IM-S AA is expected to be especially beneficial during OPDs. OPDs without IM-S allow aircraft to maximize their individual efficiencies; however, this can come at the expense of the efficiency of the overall stream. Past work has found that the vast majority of pilots find OPDs to be acceptable (Clarke, et al., 2006). However, to avoid the losing their benefits, OPDs require appropriate spacing be achieved in the en route environment so that downstream controllers are not required to intervene. Achieving this spacing can be challenging due to uncertainty in the vertical trajectory and arrival time at the FAF (due to winds and aircraft performance differences). Therefore, spacing at the start of the OPD (and potentially that realized at the end) is greater than that realized today during high density operations (Erkelens, 2000; Ren, Clarke, and Ho, 2003; Johnson, Shepley, Ferrante, and Sprong, 2009). Speed changes (e.g., through IM-S AA, Required Time of Arrivals [RTAs], controller instructions) are one way to overcome uncertainties in the vertical trajectory due to issues such as unknown winds. However, such speed change requirements can lead to undesirable changes to the vertical profile such as level segments.

Although OPDs have been implemented during light to medium density traffic operations (e.g. Louisville International Airport-Standiford Field [SDF]), some question exists as to whether they are compatible with higher traffic density operations. For example, in a Human-In-The-Loop (HITL) simulation by Johnson, Shepley, Ferrante, et al., (2009), controllers believed OPDs during high density operations may result in overtake situations. This led them to increase the spacing between aircraft when conducting OPDs and question the ability to conduct OPDs during the busiest traffic periods at Hartsfield - Jackson Atlanta International Airport (ATL). Some work has attempted to support higher density operations through changes in the design of OPDs (Tong, Boyle, and Warren, 2006; Hoffman, Martin, Pütz, Trzmiel, Zeghal, 2007). Other improvements, such as periods of off-idle descents and pilot managed spacing, have also been proposed that attempt to recover some of the loss in capacity (Ren, Clarke, and Ho, 2003; in 't Veld, van Paassen, Mulder, and Clarke, 2003). in 't Veld, et al. (2003) proposed a concept for flight deck managed separation during OPDs and noted that the ATC task of spacing aircraft during an OPD is difficult, though a pilot managed spacing task could help. The proposed concept has the pilot managing the aircraft deceleration (e.g., via flap extension management) to prevent any losses in separation.

By having aircraft manage their own spacing with IM-S AA, aircraft conducting OPDs should be able to effectively balance individual and stream efficiency and operate in a manner beneficial to the overall system. IM-S AA can be used to obtain the appropriate spacing at the entry to the OPD and to then achieve and/or maintain appropriate spacing thereafter by compensating for uncertainties during the arrival. This should allow for an increased ability to conduct OPDs due to consistent, accurate spacing and sustained capacity that would otherwise be lacking. Additionally, if IM-S AA allows aircraft to achieve a consistent spacing at the entry to the OPD and manage their spacing through the arrival, the entry spacing may be able to be reduced and the final spacing may be tighter than an unmanaged spacing without IM-S AA. Weitz, Hurtado, Barmore, and Krishnamurthy (2005) showed through fast time simulations that a concept like IM-S AA can space aircraft flying OPDs such that the inter-arrival time at the runway threshold is within +/- 10 seconds. Use of IM-S AA could prevent the early deployment of flaps or the use of speed brakes by avoiding undesirable spacing situations.

The use of a ground-only capability is expected to allow for OPD operations when demand is between 40% to 70% of capacity, and full IM-S AA should allow OPD operations at even higher levels of demand (FAA, 2007). Such expectations were demonstrated by Callantine, Palmer, Homola, Mercer, and Prevot (2006) whose fast-time simulations found that OPDs should be able to be conducted with dense arrival flows with IM-S AA and appropriate ground tools. More recent studies, such as Weitz, Katkin, Moertl, Penhallegon, Hammer, Bone, and Peterson (2012), have continued to suggest that relative spacing operations like IM-S have potentially greater throughput benefits as compared to operations only involving scheduling aircraft to fixed times over points (i.e. metering).

1.3 IM-S AA UPS Implementation

UPS' main flight operations hub and GOC are located in the vicinity of SDF. UPS next-day air operations occur late at night, local Louisville time, and include an arrival push from the United States west-coast. This stream of traffic is relatively uninfluenced by other flights and provides a reasonably controlled environment, making it suitable for initial concept development and testing.

Starting in June 2004, UPS Boeing 757 and 767 aircraft were equipped with Cockpit Displays of Traffic Information (CDTIs) depicting ADS-B and Traffic Alert and Collision Avoidance System (TCAS) traffic. The equipment was approved for basic traffic awareness, including “see and avoid in visual conditions” and “traffic awareness in all weather conditions.” Additional traffic awareness provided by the CDTI has already allowed UPS to reduce its distance flown in the terminal area by approximately four miles in the standard landing configuration (FAA, 2005).

UPS has also tested OPDs at SDF that allow an aircraft to remain at or near flight-idle thrust from the Top of Descent (TOD) to the FAF. To accomplish OPDs, aircraft need to be spaced and sequenced prior to descent as well as throughout the arrival. The requirement for the SDF OPDs is that aircraft be initially spaced approximately 20 NM apart. Delivering that interval in the final airspace prior to starting the OPD proved to be a challenging and inefficient operation within current ground operations. Therefore, UPS determined that some capability was necessary to set-up and then manage intervals during OPDs. The identified need aligned with FAA goals and so a series of joint FAA and industry activities were initiated.

This section describes the specific IM-S AA operation that was implemented by UPS during OPD arrivals and approaches. There are some differences from the current IM-S AA concept, which are noted. Though at the time the UPS operation was termed Flight Deck Merging and Spacing (FDMS), for simplicity this paper continues to use the term IM-S AA.

1.3.1 Pre-Approval Development Activities

In part to resolve the OPD issues but also to add new capabilities, UPS and ACSS announced a partnership to develop equipment for a set of ADS-B in applications in June of 2005. Called SafeRoute, the equipment included functionality for the early IM-S AA implementation as defined by FAA (2008). For the next few years, several activities occurred in an FAA-sponsored, FAA and Industry group: the specific concept was matured, safety and performance analyses were developed, and simulations and demonstrations were conducted. The group was supported at various levels by organizations such as the FAA, UPS, ACSS, Boeing, Honeywell, NASA, EUROCONTROL, MITRE, RTCA, and others.

Starting in September 2005, several versions of the application description were developed, with the final being released in February 2008 (FAA, 2008). During 2007, the group also developed several versions of a Preliminary Hazard Assessment (PHA). The work done on this material pointed to open questions that were either debated until reaching consensus or analyzed through studies. Section 1.3.5 describes HITL simulation activities conducted to answer some of the open questions that arose as part of the concept development.

1.3.2 Background Research

1.3.2.1 Previous Flight Deck IM-S AA Findings

Previous HITL simulation research found IM-S AA was compatible with current operations (e.g., Hebraud, Hoffman, Papin, et al., 2004; Oseguera-Lohr, et al., 2002; Hebraud, Hoffman, Pene, et al., 2004). Work done by Hoffman, et al., (2007) specifically looked at IM-S AA during OPDs and found that pilots reported compatibility with current operations and compatibility between IM-S AA and OPDs.

In previous research on similar spacing concepts (Oseguera-Lohr, et al., 2002; Hebraud, Hoffman, Papin, et al., 2004; Hebraud, Hoffman, Pene, et al., 2004; Hoffman, et al., 2007), pilots reported similar to slightly higher but acceptable workload as compared to current operations. Although in Hebraud, Hoffman, Pene, et al. (2004) where the spacing concept was examined to the FAF, some participants wondered if the workload would be higher in a more realistic environment.

In evaluations of spacing tasks, pilots reported a better understanding of the situation (Hebraud, Hoffman, Papin, et al., 2004; Hoffman, et al., 2007) and the ability to anticipate (Hebraud, Hoffman, Pene, et al., 2004). However, Hebraud, Hoffman, Pene, et al. (2004) did report that one pilot thought that situation awareness could be worse due to a focus on the Target Aircraft and neglect of other duties.

Concepts that require the use of an additional display will likely increase head-down time and add to the instrument scan. The head-down time should not increase to an unacceptable level. In Oseguera-Lohr, et al. (2002), pilots conducting a spacing task reported an increased but acceptable amount of head-down time. In Hebraud, Hoffman, Papin, et al. (2004) and Hebraud, Hoffman, Pene, et al. (2004), pilots reported some concerns about focusing too much on the new displays and a reduced scan.

The displays and the associated information are critical to the conduct of IM-S AA. Previous research with varying levels of information on the display reported general acceptance with some suggestions for improvements (e.g., Hebraud, Hoffman, Papin, et al., 2004; Hebraud, Hoffman, Pene, et al., 2004; Oseguera-Lohr, et al., 2002; Hoffman, et al., 2007).

Field tests have also been done on IM-S AA. IM-S AA distance-based spacing tasks were examined during flight tests at the Airborne Express hub in Wilmington, Ohio in 1999. The event was called Operational Evaluation 1. The applications of station keeping and in-trail or lead climbs and descents were examined (FAA, 2000). Flight crews were asked to maintain an in-trail spacing distance from a Target Aircraft while remaining level, climbing, or descending. Pilots found the concept and the required workload to be acceptable. Pilots also reported that the CDTI assisted in the spacing task and that it aided in maintaining situation awareness. (Battiste, Ashford, and Olmos, 2000).

Operational Evaluation 2 was conducted at the UPS SDF hub in 2000. IM-S AA was examined as both initial approach spacing and final approach spacing. ATC remained responsible for separation (FAA, 2001; Joseph, Domino, Battiste, Bone, and Olmos, 2003; Garloch, 2001). After leveling off at the assigned speed and altitude, flight crews were required to achieve and maintain a set distance within specified tolerances on an arrival procedure in the terminal environment prior to joining final approach and starting final approach spacing. Information available to the flight crews included distance to the Target Aircraft in tenths of a NM as well as Target Aircraft and ownship ground speed information. Pilot answers were favorable for the initial approach spacing task, which was conducted in the en route phase of flight. Flight crews reported a need for procedures specifying flight crew and ATC responsibilities as well as a need for improved phraseology. There were indications that the workload could be high for a spacing task and that a reduction would be beneficial. For the final approach spacing task, pilots flying the concept with IM Speeds reported, on average, a need to reduce the associated workload. Workload was reported as high due to the frequency and magnitude of the IM Speeds.

Lohr, et al., (2005) conducted a flight test to evaluate IM-S AA with a time-based ASG. Three aircraft were flown in Chicago O-Hare (ORD) airspace during late night operations. IM Speeds were either flown through manual throttle control or through auto-throttle inputs. All participants were research pilots and flew both Area Navigation (RNAV) and non-RNAV arrivals in the terminal area under nominal conditions. As part of the concept, the ASG to-be-achieved as the Target Aircraft crossed the threshold was intended to be assigned by ATC. This was not done for the evaluation; however, as it was not intended to be a test of ATC. ATC was responsible for maintaining separation.

In this test, the ASG of 90 seconds was achieved with an average of 90.8 seconds and a standard deviation of 7.7 seconds. No difference in spacing delivery was observed when either flying the speeds manually or when they were coupled to the auto-throttle. However, pilots reported the manual condition as having higher workload. Subjective data was gathered in approximately 50% of the runs. Pilots reported that the tool was acceptable, and workload during the RNAV arrivals was slightly higher than current conditions. Pilots also reported higher, but still acceptable, head-down time as compared to current operations.

In OPD-alone operations, Clarke, et al. (2006) reported that pilots expressed an increase in workload due to the high head-down time required for monitoring and managing and unexpected lead aircraft behavior.

1.3.2.2 Previous ATC IM-S AA Findings

Fundamental to the ATC task is keeping cognizant of current and evolving conditions i.e., maintaining situation awareness (SA). When aircraft are conducting IM-S, controllers are less actively involved in aircraft speed control. The impact of this on controller performance, monitoring, and the ability to intervene must be examined. Previous studies have indicated that monitoring of aircraft under flight deck spacing operations was increased for non-spacing aircraft in a spacing stream (Mercer, et al., 2005), but reduced for aircraft that had been sequenced and were maintaining their spacing (Aligne, et al., 2003). Regardless of the impact on monitoring, there did not appear to be an effect on safety or a loss of SA. A summary report of several European IM-S AA simulations (Hebraud, et al., 2006) reported on a study of Italian airspace that found improved SA of controllers when using AMAN and IM-S AA, which also led to improved coordination between controllers. Grimaud, et al. (2003) assessed controller SA when conducting IM-S AA under normal conditions (i.e., no abnormal events were introduced) from the en route to the initial portion of the Terminal Radar Approach Control (TRACON). They found, even with high traffic demand, controllers were able to maintain SA through the ability to anticipate, focus on relevant tasks, and gather information.

Related to SA is the controllers trust in the IM-S operation. They must fully understand the objectives and methods IM-S uses to achieve and maintain spacing and they must be able to trust that flight crews will properly follow the IM Speeds. The degree to which their mental models conform to the reality of IM-S operations allow them to appropriately calibrate their level of trust as conditions change. For example, if IM-S usually proceeds in a predictable fashion, but one aircraft starts deviating from the expected procedures, controllers will more likely be able to detect the situation and intervene before it escalates. Over-trust where the controller neglects the IM Aircraft must also be prevented (Grimaud, et al., 2003).

Since IM-S shifts some workload involved in aircraft speed management and spacing to the flight crew, it should reduce controller workload through a reduction in the number of required instructions and a reduction in communication. Grimaud, et al. (2001) examined IM-S AA in the ETMA (en route to the IAF) with distance-based criteria. Through questionnaires, controllers reported lower workload with delegation and the highest workload with the decision of delegation and communication of instructions. Other measures in this work indicated a trend toward equal or lower workload. Similarly, in Grimaud, et al. (2003), all controllers noted a workload reduction for a simulation of IM-S AA in the ETMA with distance-based criteria. Integrating flows and building the sequence were two of the most demanding tasks.

Aligne, et al., (2003) examined IM-S AA with both distance and time-based criteria from a controller perspective in the ETMA. The majority of controllers reported a reduction in their workload with IM-S AA in place. Aligne, et al. (2003)'s data was later analyzed by Cloarec, Purves, and Vergne (2004) in order to examine controller workload with respect to five main tasks: conflict search (ensuring new action does not put separation at risk), flight data management (e.g., managing strips), coordination with other ATC entities, communication, and radar activity (conflict resolution and monitoring). They found workload reductions in the executive (i.e., R) controller of 17%, mainly for the tasks of radar activity and communication.

Mercer, et al. (2005) found that ATC workload was acceptable for a similar concept for conditions in which they both had and did not have new spacing tools. Although participants reported higher workload in the condition where pilots-only had new spacing tools (versus controller only spacing tools, pilot and controller spacing tools, and no spacing tools), this was not in agreement with their workload ratings that were gathered at five minute intervals where the pilot-only spacing tool condition was sometimes lower workload and the controller-only tool condition was higher workload. The authors hypothesized that this was due to controllers desiring as much information as possible and finding the task of maintaining separation responsibility, after spacing delegation, as high workload.

In a flight test / demonstration, TRACON controllers reported lower workload when monitoring aircraft performing a spacing task on a structured arrival versus actively vectoring aircraft (FAA, 2001). A summary report of several European IM-S AA simulations (Hebraud, et al., 2006) reported on a study of Italian airspace that found reduced workload for controllers receiving aircraft already conducting IM-S AA but workload within acceptable limits for controllers setting up IM-S AA. This is supported by Rhodes and Rhodes (2001), who noted that MIT restrictions can lower workload levels for the controllers receiving aircraft in-trail. However, the workload of the controller establishing the MIT restriction can increase. Hebraud, et al. (2006) also reported that the reduction in workload allows controllers to concentrate of other tasks such as strategic activities and detection of conflicts.

Boursier, et al. (2005) noted similar workload for AMAN and IM-S AA operations over AMAN alone operations. However, a greatly reduced number of instructions suggested a significant reduction in communications. The lack of a workload reduction for some controller positions was related to having to cancel IM-S AA as separate flows converge on a merge point.

Reducing controller workload may allow controllers to handle a larger number of aircraft in their sector. Grimaud, et al. (2001) reported that IM-S AA allowed controllers to handle more traffic without becoming overloaded and to anticipate decisions and actions. Boursier, et al. (2005) found increased throughput of two more aircraft per hour with AMAN and IM-S AA over scenarios with AMAN alone.

Overall, most of the past research reported that controllers found the concept to be acceptable and beneficial under normal conditions (e.g., Boursier, et al., 2005; Hebraud, et al., 2006). Research has also shown high rates of use when used at controller discretion (Hebraud, et al., 2006). Of the limited research that examined non-normal situations, Boursier, et al., 2006 found controllers didn't have difficulty with detecting or managing issues such as an abnormal overtake by the IM Aircraft. Controllers in the experiment were also able to manage mixed IM-S AA equipages. Prior to the simulation work, these issues were expected to be major challenges. The simulations, however, proved them to be more manageable than expected.

1.3.3 Concept Overview

This section summarizes the initial UPS implementation as defined in the application description (FAA, 2008). Not all aspects of the UPS Implementation described in this section necessarily apply to the current IM concept as described in RTCA (2015) and FAA (2015). One of the primary differences between the UPS implementation and the current IM-S AA concept is the role of ATC. For the UPS implementation, the operational parameters were pre-coordinated between ATC and the UPS GOC. The GOC then provided an IM initiation message to an IM Aircraft when it was approximately within ADS-B range of its intended Target Aircraft. As described earlier, the role for ATC in the current IM-S concept is to set up the aircraft pairs and initiate the IM operation by issuing a clearance. Ground automation is expected to be in place to identify the candidate aircraft pairs, generate the relevant information for the clearance, and provide monitoring information. One other significant difference is that the achieve-by point in the UPS implementation was placed close to the TOD. IM Aircraft then maintained their spacing through the descent and approach. Most IM-S AA scenarios in the current concept locate the achieve-by point at or near the FAF such that the majority of the operation involves achieving the spacing, with only a short maintain period on final. From a flight crew perspective, however, the UPS implementation and the current IM-S AA concept remain very similar.

1.3.3.1 UPS Implementation: Procedures

The UPS IM-S AA operation started when a decision was made to conduct IM-S AA between a pair of aircraft. First, an initiation message was uplinked via data link (i.e., Aircraft Communications Addressing and Reporting System [ACARS]) from the GOC. The message information was pre-coordinated between the GOC and appropriate ATC facilities and included the flight identification of the Target Aircraft, the common merge waypoint (achieve-by point), and the ASG. The avionics were designed to stop displaying IM Speeds when the aircraft crossed 1500 ft AGL and all parties expected this to occur approximately at the FAF. Therefore, that point was not communicated in the message.

After receiving the message, the flight crew could choose to not conduct IM-S AA based on other operational requirements. If the IM-S AA initiation message was rejected, the flight crew continued non-IM-S AA operations and did not need to contact the GOC. If the initiation message was accepted, the flight crew replied with an acknowledgement that implied they received the message and planned to conduct IM-S AA. The IM-S AA transition was complete once the flight crew entered the initiation message elements into the FIM equipment and the GOC received the acknowledgement message (regardless of whether IM-S AA was actually initiated). Entry of the information and flight crew activation armed the FIM system, which was annunciated to the flight crew.

After the set-up and the aircraft were within ADS-B range of each other, the FIM flight deck system provided IM Speeds that fine-tuned the spacing interval by targeting the ASG. The FIM system could provide IM Speeds outside the aircraft speed envelope based on the aircraft's current configuration. It was then up to the flight crew to determine whether to fly the IM Speed, configure the aircraft so that the IM Speed could be flown, or reject the IM Speed as is done today with ATC speed instructions. With the presentation of each IM Speed, the flight crew ensured that the IM Speed was feasible given the current configuration and conditions.

Standard procedures for notifying ATC of speed changes were in effect. This application did not change any existing requirement or introduce new speed change notification procedures. When appropriate, the flight crew implemented the speed through entry in the Mode Control Panel (MCP) or Flight Management System (FMS). The flight crew followed the IM Speeds from the en route environment and allowed ownship to gradually close on the ASG as it flew to the achieve-by point and joined an OPD. After the achieve-by point, the flight crew flew IM Speeds to maintain the ASG.

The IM Speeds were provided until the IM Aircraft reached approximately the FAF, at which point the IM Speeds were no longer displayed. The flight crew discontinued following IM Speeds, slowed to the Final Approach Speed (FAS), and configured the aircraft for a normal landing using conventional means.

The UPS IM-S AA implementation did not preclude ATC from providing a speed or heading instruction to either aircraft at any time. However, ATC-initiated speed or heading instructions to either the IM or Target Aircraft does affect IM-S AA. If the IM Aircraft received a vector from ATC, the flight crew flew that heading and deactivated the IM-S AA function. This results in the system disengaging and no longer providing IM Speeds. If the flight crew did not manually initiate disengagement, the FIM system detected the deviation and automatically discontinued providing the IM Speed. IM-S AA stopped at that point and the flight crew continued to fly the last IM Speed. If the IM Aircraft was given a speed instruction from ATC, the flight crew flew that speed and deactivated the IM-S AA function. After disengaging, flight crews were expected to fly speeds issued by ATC or as required by procedure.

If the Target Aircraft received a vector from ATC, the FIM system detected the deviation from the expected flight path, disengaged, and discontinued the display of IM Speeds. The annunciation of disengaging and the discontinued display of IM Speeds was the indication to the IM Aircraft flight crew that the Target Aircraft deviated and IM-S AA was terminated. The flight crew was not expected to detect this event on a display such as a CDTI.

ATC altitude instructions did not terminate IM-S operations, nor did an ATC speed instruction to the Target Aircraft.

1.3.3.2 UPS Implementation: ATC Responsibilities

When IM-S AA was being conducted, ATC had knowledge of IM-S AA operations and continued to monitor and be responsible for separation for all aircraft. The GOC informed ATC of IM-S AA capable aircraft.

Flight crews notified ATC of IM-S AA conduct and termination. ATC provided normal clearances as required for the arrival and approach operations and acknowledged flight crew notification of IM-S AA operations.

ATC responsibilities did not change when IM-S AA was being conducted. Controllers continued to monitor and be responsible for separation for all aircraft. The ASG between successive arriving aircraft at any point matched or exceeded the distance needed by the controller prior to handoff to a downstream sector, as well as that needed in the terminal area and upon landing. If ATC required spacing changes from that planned for at the start of IM-S AA, ATC intervened using speed instructions and/or vectors to achieve their desired spacing. ATC also intervened in the event of a spacing or separation issue with a non-participating aircraft. As described earlier, speed or heading instructions from ATC terminated IM-S AA for the affected aircraft. If at any time ATC decided IM-S AA should be discontinued, there was a return to regular operations without IM-S AA for the affected aircraft. ATC coordinated on an acceptable ASG on a daily basis with the GOC prior to IM-S AA operations and informed the GOC if the requested ASG was in conflict with its spacing and / or separation requirements.

En route and terminal controllers monitored the operation, but allowed it to be conducted without input to the extent that separation or spacing did not become a factor. As they do normally, controllers received and, if appropriate, cleared the flight crews for any heading or speed requests. ATC was also expected to attempt to prevent non-participating aircraft from interfering with IM-S AA operations to the extent possible. For example, if ATC desired to resolve a situation between two aircraft and did not have a preference for which aircraft path was modified, the controller was expected to modify the path of the non-IM-S AA aircraft. ATC was also expected to avoid instructions contradictory to IM-S AA, unless necessary. For example, ATC was not expected to offer a routing that conflicted with the IM-S AA routing, such as taking an aircraft off the OPD. ATC required an understanding of the goals and desires for IM-S AA to fulfill these desired outcomes.

1.3.3.3 UPS Implementation: Flight Crew Responsibilities

Flight crews interacted with on-board systems to conduct IM-S AA. Flight crew responsibilities were to fly the IM Speeds, when appropriate, and monitor for annunciated equipment-related failures. The flight crew was expected to follow the IM Speeds except when operational limitations exist or when receiving contrary instructions from ATC. The flight crew was required to discontinue flying IM Speeds and to disengage the IM-S AA system upon receiving an ATC speed or vector instruction. Should IM Speeds no be longer provided, the flight crew was expected to continue to fly their current speed until instructed to fly a controller-issued or procedurally required speed. The flight crew was not responsible for monitoring a display such as a CDTI to detect separation issues related to the Target Aircraft. The flight crew was required to notify ATC that they had begun or terminated IM-S AA (see Phraseology in Section 1.3.3.5). However, in this initial implementation where the GOC was providing the initiation information, the flight crew did not contact ATC to request support for IM-S AA operations as ATC did not have the appropriate information to assist[2]. The flight crew only contacted ATC when announcing the conduct or termination of IM-S AA.

The FIM equipment could provide IM Speeds outside the aircraft speed envelope based on the current configuration. The flight crew decided if the IM Speed could be safely implemented and then took the appropriate action to either fly or disregard the IM Speed. This is similar to non-IM operations, where ATC provides speed instructions and the crew must decide whether to accept or reject the instruction. Normal procedures for notifying ATC of speed changes remained in effect.

The flight crew could terminate or choose not to participate in IM-S AA at any time should operational requirements or safety reasons prevent participation. Upon termination, the flight crew notified ATC, and ATC then determined the appropriate action. If at any time the flight crew was not able to follow the IM Speed, the crew maintained their present speed until they were able to fly the IM Speed or they disengaged the FIM system.

[2] Note that this is only applicable to an initial, GOC-centric implementation such as the UPS implementation. The current IM-S concept relies on ATC to provide the IM initiation clearance.

1.3.3.4 UPS Implementation: GOC Responsibilities

The GOC filed the appropriate flight plans that included any necessary information on FIM equipage. It then coordinated with the ATC facilities that IM-S AA operations would be in effect, the aircraft that were capable of performing IM-S AA, and the planned ASG between aircraft pairs[3]. The GOC used a ground-based tool[4] to set the aircraft sequence and to determine which aircraft pairs transitioned to IM-S AA. The GOC sent an initiation message to the flight crew with the appropriate information to transition to IM-S AA via data link (i.e., ACARS). If the flight crew requested clarification, the GOC sent another initiation message. After sending the second initiation message or if no second transmission occurs, the GOC tasks were complete.

1.3.3.5 UPS Implementation: Phraseology

IM-S AA involved new phraseology for use by the flight crew. “Company spacing” was used to indicate both that a spacing task was occurring, that it was “company” specific, and that others could not request the operation. The flight identification of the Target Aircraft and the ASG were not used in the voice communications.

When the flight crew started IM-S AA or checked on to a new frequency, they provided a notification to ATC with the following phraseology:

1. *“[ATC facility], [Ownship call sign], [altitude], company spacing.”*

After this notification, ATC was expected to acknowledge the notification with the following or similar phraseology:

2. *“[Call sign], [ATC facility], Roger.”*

If the flight crew had to terminate IM-S AA (at point other than normal termination point around the FAF), they notified ATC with the following phraseology:

3. *“[ATC facility], [Ownship call sign], terminating company spacing.”*

After this notification, ATC was expected to acknowledge the notification with the following or similar phraseology:

4. *“[Call sign], [ATC facility], Roger. [Instructions as necessary]”*

If ATC terminated IM-S AA via a vector to ownship (which then provoked flight crew manual disengagement), the flight crew would not announce the termination since it was assumed that ATC had intended for the operation to terminate.

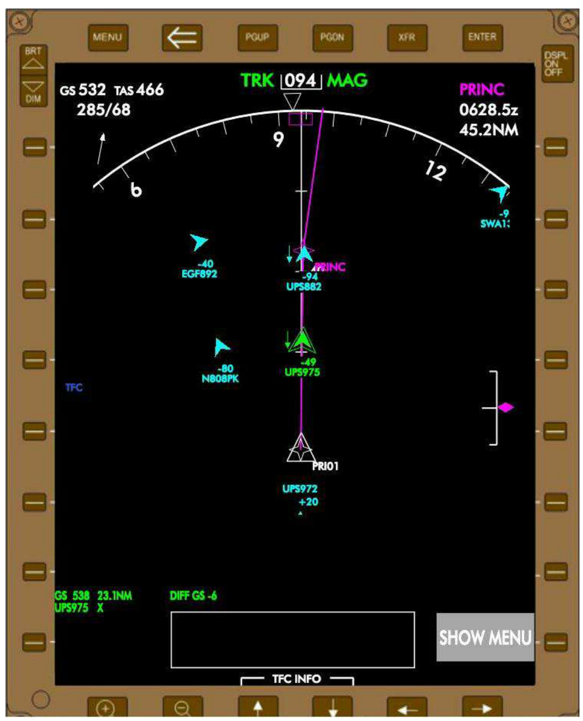
[3] Methods of informing ATC include Letters of Agreement (LOAs) and entry of information in the flight plan.

[4] Although a GOC-based setup tool was prototyped to facilitate the UPS operation, responsibility for IM setup in the current IM-S concept is allocated to ATC (FAA, 2015).

1.3.4 ACSS SafeRoute Development and Certification

ACSS participated in the FAA / industry group that was part of the process of developing and certifying their SafeRoute equipment for IM-S AA (as well as CDTI Assisted Visual Separation [CAVS] during Visual Approach and the display of a surface map with traffic). The SafeRoute system included a CDTI hosted on a Class III Electronic Flight Bag (EFB) as well as an ADS-B Guidance Display (AGD).

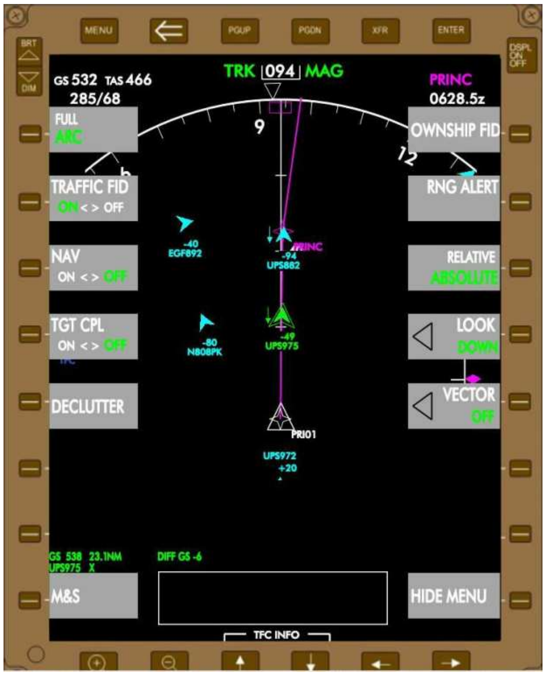
For IM-S AA, the CDTI was used to enter the required initiation data and was also intended to be a situational awareness tool during IM-S AA conduct. It included a Target Aircraft selection capability which highlighted a particular aircraft of interest and presented additional information on that target (i.e., aircraft category, third party call sign, range, and ground speed), as shown in the lower left corner of the display (Figure 1-2).



MITRE

Figure 1-2. CDTI Interface with Target Selected

Line select keys (Figure 1-3) provided access to the setup page (Figure 1-4), which is where the ASG (“Space Interval” on the display) and achieve-by point identifier (“Merge Waypoint” on the display) were entered. Once IM-S AA was initiated, the CDTI displayed a fast / slow bug, the spacing deviation indicator (or “picnic table”), as well as the IM Speed and current Indicated Air Speed (IAS) in Mach (M) or knots (kts) (Figure 1-5). The fast / slow bug presented current airspeed or Mach number relative to the IM Speed, and the picnic table graphically portrayed the current aircraft position relative to the position required to achieve or maintain the ASG.

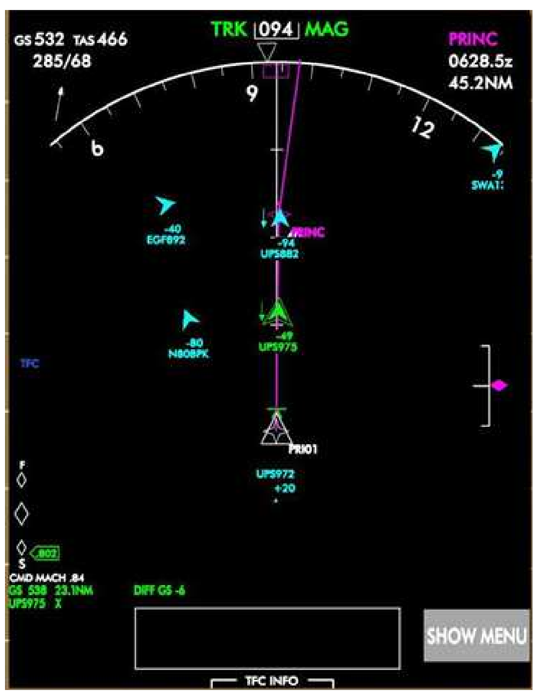


MITRE

Figure 1-3. CDTI Function Menu

ACSS

Figure 1-4. CDTI IM-S AA Setup Page



MITRE

Figure 1-5. CDTI Interface with IM-S AA Enabled

The IM Speeds were driven by an on-board algorithm that was based on work done by EUROCONTROL on a Co-Space time-history algorithm (EUROCONTROL, 2006). It attempted to achieve and maintain a fixed, time-based spacing interval and was normally quantized at M0.01[5]. Despite the quantization, IM Speeds were not always given at those increments as the FIM equipment had logic that tried to avoid numerous, smaller IM Speed changes in favor of fewer, larger IM Speed changes. In the achieve mode, the FIM equipment provided IM Speeds to reach the ASG at the achieve-by point. After the achieve-by point, the maintain mode became active and the FIM equipment provided IM Speeds to remain at the ASG. The ASG was given in time, so the time to maintain remained constant. However, the distance between the aircraft decreases as the aircraft decelerate for the arrival and approach to landing. Therefore, maintaining 145 seconds may be seen as a distance of approximately 20 NM at the start of the OPD, which becomes a distance of 5.5 to 6 NM on final approach.

The SafeRoute display of IM Speed values contained upper and lower speed boundaries. The maximum / minimum Mach values (M0.84 / M0.50) were provided to the system via stored configuration parameters. The maximum Calibrated Airspeed (CAS) value was the Maximum Allowable Speed received from the Air Data Computer (ADC). The minimum CAS value was the Minimum Maneuvering Speed provided by the FMS. Below 11,000 feet (ft), the system limited the maximum IM Speed to 250 kts and limited the minimum IM Speed to 20 kts below the FMS-provided Minimum Maneuvering Speed. When the thresholds were reached, the speed used in the speed logic and the displayed IM Speeds were limited to these values. However, the equipment did not provide an indication to the flight crew when the IM Speed was limited to the maximum or minimum value.

A second display allowed for the presentation of key parameters in the pilot's forward field of view. This display, designated as the AGD (Figure 1-6), was mounted to the underside of the MCP (Figure 1-7). The AGD provided two information fields for IM-S AA: IM Speed (labeled CMD SPD on the equipment) and horizontal distance between ownship and the Target Aircraft (labeled TGT DIST).

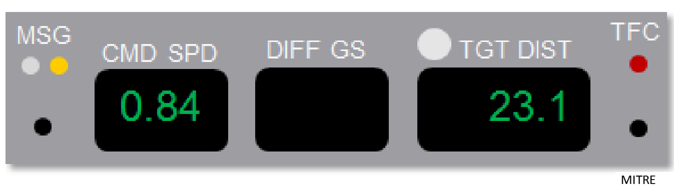


Figure 1-6. ADS-B Guidance Display (AGD)

Whenever an IM Speed appeared, the CMD SPD value field would begin flashing, indicating that crew action was required. A speed was then to be selected by the flight crew via the MCP. Inputting a speed canceled the flashing. The flashing could also be cleared early by pressing a button on the left side of the display. The IM Speeds on the AGD followed the same quantization logic as the CDTI. The display field labeled "DIFF GS" was not used during the IM operation.

[5] Although the KIAS quantization value was suggested by ACSS to be 15 kts, several IM Speeds were observed outside of 15 kt multiples (see Section 4.5).

ACSS received Supplemental Type Certification (STC) for SafeRoute use in the UPS Boeing 757 aircraft in July 2007 and for use in the UPS Boeing 767 aircraft in July 2008. Figure 1-7 shows the location of each of the displays in the B757 cockpit. The B767 cockpit installations are similar.

Figure 1-7. B757 IM-S AA Display Locations

1.3.5 IM-S AA Initial Implementation HITLs

While previous research existed on similar spacing and separation concepts, none had specifically examined the initial implementation in its intended environment. To address this need, MITRE conducted a series of human-in-the-loop experiments from 2006 through 2007 to evaluate the initial implementation from the perspectives of pilots (Bone, Penhallegon, and Stassen, 2008a; Bone, Penhallegon, and Stassen, 2008b) and controllers (Bone, et al., 2007; Penhallegon and Bone, 2009) in both the en-route and terminal domains using a cockpit-based, time-history algorithm (like that mentioned in Ivanescu, Shaw, Hoffman, and Zeghal, 2005). The IM-S AA procedures and environment simulated were based on the most current versions of the application descriptions available at the time (e.g., FAA, 2006). As the simulations were intended to validate the initial implementation, they considered operations with a single airline using aircraft types with similar performance (i.e., Boeing 757s and 767s) joining a single arrival and approach.

The simulations were used to answer questions and address issues that arose during the development of the application description and the PHA. They built on past research into IM-S AA, but examined open issues and new topics introduced by the proposed implementation (e.g., the role of ATC versus an Airline Operations Center [AOC]). The results of the simulations fed back in to those materials and helped mature the specific implementation as described in Section

1.3.3. The simulations started in environments believed to be less complex and then, as lessons were learned, transitioned to more complex environments. Each simulation built on the previous work's lessons learned. The key research issues included:

- Assessing pilot and controller usability and acceptability,
- Assessing the robustness of the procedures and operations to off-nominal events, and
- Validating that a time-history spacing algorithm implementation is acceptable for an OPD environment.

En route merge and remain-behind-during-OPD operations were evaluated in separate simulations. Flight crew and controller evaluations were also conducted separately. The flight crew simulations were termed Flight Deck-based Merging and Spacing (FDMS) 2 and FDMS 3 and the controller simulations were termed FDMS 1 and FDMS 4 (with the names reflecting the sequential order). All experiments tested IM-S AA procedures under nominal and off-nominal situations that included events such as spacing disruptions, re-route requests, and equipment failures.

1.3.5.1 Flight Deck Experiments

FDMS 2 evaluated IM-S AA during an en route merge operation from a pilot perspective (Bone, et al., 2008b). FDMS 3 evaluated the impact of FDMS on the flight deck during arrival (specifically an OPD) and approach operations under both normal and non-normal conditions (Bone, et al., 2008a). The CDTI used in the simulation was similar to the SafeRoute system as described in Section 1.3.4. The simulated AGD contained similar information as that shown in Figure 1-6; however the presentation of new IM Speeds and alerting logic differed from the final, fielded system.

The participants from both flight deck experiments reported that overall, IM-S AA was acceptable, that it slightly increased workload over operations without IM-S AA (but not to an unacceptable degree), and that it allowed for acceptable traffic awareness. None of the participants in either experiment reported that IM-S AA presented an unreasonable level of difficulty. All participants for both evaluations reported being able to understand, achieve, and comfortably maintain the spacing interval. Some variability existed in relation to the number of IM Speeds; however, even with IM Speed acceptance rates less than 100%, the ASG was achieved in both domains to within approximately two seconds. This suggests that the concept and similar algorithm behavior are robust to varying levels of pilot IM Speed acceptance.

Results from the off-nominals for both evaluations suggest that clear procedures and phraseology for disruption situations need to be defined so that there is no ambiguity between actions the flight crew needs to take and what is expected of ATC. Phraseology and procedures were developed after these simulations in the application description.

Overall, the experiments demonstrated that IM-S AA was acceptable and compatible with flight deck operations in the en route and terminal domains. IM-S AA can help increase spacing stability in an arrival flow, particularly during an OPD. Despite a slight increase in workload, most pilots reported no negative effects from performing IM-S AA in a simulated environment and did not anticipate any major issues when IM-S AA is introduced in the field.

1.3.5.2 ATC Experiments

The first simulation, FDMS 1, evaluated IM-S AA during an en route merge operation from the ATC perspective (Bone, et al., 2007). It found general acceptability and improvements over current-day operations under normal and off-nominal conditions. In comparison to current-day operations, IM-S AA showed a reduction in (1) the number of controller-issued maneuvers, (2) the number of communications, and (3) controller workload. A reduction of situation awareness was not observed. Some variability existed as to issues related to monitoring and interventions.

The final simulation, FDMS 4, examined IM-S AA from the en route controller perspective during the arrival from the TOD to handoff to the terminal area (Penhallegon and Bone, 2009). Whereas FDMS 1 examined the ATC en route merge environment, FDMS 4 was specifically concerned with the merge and arrival. Controllers reported on average that IM-S AA was acceptable, desirable, and an improvement in operational efficiency. IM-S AA allowed for acceptable workload and traffic awareness – even in the event of spacing disruptions. Controllers had no issues intervening with IM-S AA aircraft when necessary. IM-S AA helped reduce overall controller interventions in an arrival stream under normal conditions, but did not increase or decrease total interventions for overall sector traffic sets under normal conditions or when spacing disruptions were introduced.

Feedback from these simulations validated that with AOC setup of the operation, ATC would be able to sufficiently maintain positive control of the aircraft and intervene when necessary. Simulation results also led to the development of phraseology for pilots informing controllers of the start and abnormal termination of IM-S AA.

1.3.5.3 Related Activities

MITRE also conducted a series of lab demonstrations with FAA Flight Standards and Certification individuals in 2006 and 2007 (e.g., Bone and Penhallegon, 2006). The purpose of the demonstrations was to provide key FAA certification and flight standards individuals an initial look at IM-S AA from the flight deck perspective. The feedback from the demonstrations was used for concept and display development, as well as to determine topic areas for future study.

While the IM-S AA work was being conducted, a parallel activity developing and testing supporting ground automation was also conducted (summary provided in Moertl and Pollack, 2011). The ground tools supporting the flight deck capability are believed to be important to some IM-S implementations and continue to be developed by the FAA for ATC automation.

1.3.6 UPS Operational Approval and IM-S AA during OPD Operations into SDF

After development activities and SafeRoute 757 certification in July 2007, UPS received operational approval for the equipped 757 aircraft to use the SafeRoute applications in December of 2007. The first flight of IM-S AA occurred on January 17, 2008. UPS then received SafeRoute 767 certification in July 2008, followed by operational approval in February of 2009. In total, six 757 and five 767 aircraft were equipped with SafeRoute.

UPS and the associated ATC facilities conducted IM-S AA for aircraft flying from the various western United States cities into its main hub at SDF (Figure 1-8) via one merge fix (achieve-by point), one arrival (i.e., OPD), and one approach to one runway (Figure 1-9). For the ASG, participants decided to use a time-based interval of 145 seconds, which was expected to result in a distance of approximately 20 NM between aircraft at the start of the OPD and then continue to reduce to a distance of 5.5 to 6 NM as the Target Aircraft touched down. This ASG is intentionally well outside the minimum separation required between two 767 aircraft and operational experience may allow for a reduction of the ASG.

For this implementation, IM-S AA initiated approximately 300 NM from the achieve-by point and terminated at approximately 1500 AGL (i.e., around the FAF). During the merge (achieve) phase, Kansas City Center (ZKC) controlled the majority of the aircraft. Indianapolis Center (ZID) then controlled the aircraft as they began the OPD, and Louisville TRACON controlled the aircraft as they arrived at SDF. A time-based ASG was used that achieved and then maintained from the en route environment into the terminal domain. Pairs of IM-S AA aircraft were formed into linked chains by allowing an IM Aircraft in one pair to be a target for its following aircraft, provided that all aircraft in the chain were appropriately equipped.

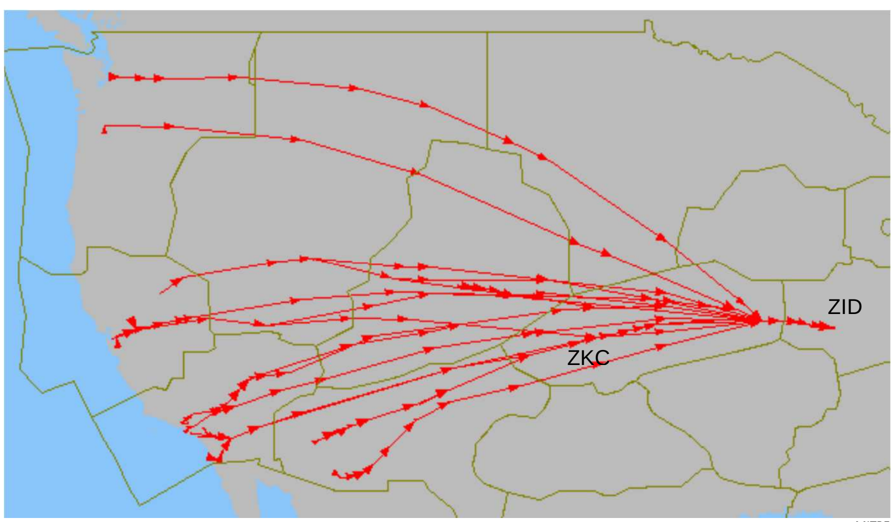


Figure 1-8. UPS West Coast Arrival Bank

FAA / adapted by MITRE

Figure 1-9. UPS IM-S AA Domain

After the first flight in 2008, UPS conducted IM-S AA during OPDs approximately once a week due to limited number of equipped and available aircraft, limited number of trained pilots, and some technical issues with certain aircraft installations (not related to the FIM functionality). In 2009, UPS conducted IM-S AA during OPDs as 767s become equipped, but on a less frequent basis than was done in 2008. After 2009, only select flights conducted IM operations, including those for this field test in 2010.

1.3.7 UPS Small Group Tryout

In order to provide data on operational acceptability, spacing performance, human factors, and other topics back to the concept and equipment developers, the FAA's SBS Program Office initiated a data collection activity to further examine IM-S AA in the field. Data was not collected during the 2008 and 2009 flights as a formal test environment was not yet in place. A pre-field test event, called the Small Group Tryout (SGT), was conducted in 2009 and was intended to help prepare for a more extensive data collection activity, which is the subject of this report.

The SGT was conducted on two nights in April of 2009, testing both the ground and flight-deck-based components. It had three main goals:

1. Validate and mature data collection tools and procedures for a later, more comprehensive test of the IM-S AA,
2. Provide first-look information about ground setup and IM-S AA initial performance and human factors issues, and

3. Practice the logistics associated with positioning aircraft, crews, and observers for a later, more comprehensive test.

Four out of six FIM-S equipped flights were generally successful in achieving and maintaining their ASG (145 sec) throughout the descent and arrival. Some ADS-B data issues with UPS Boeing 757 Target Aircraft appeared to result in more variable spacing performance and greater numbers of IM Speeds. Additionally, some aircraft were successfully maintaining the ASG until late in the arrival. However, pilots felt it was inappropriate to respond to some speed-up IM Speed changes after starting to configure the aircraft for landing. As a result, final spacing for these aircraft was greater than it otherwise would have been.

The ZKC controllers appeared to be comfortable with IM-S AA. The ZID controllers were also positive and had no issues with flights conducting IM-S AA during OPDs. They reported that IM-S AA slightly reduced their workload and communications and claimed that they are less likely to issue speed and heading changes with IM-S AA unless weather interferes.

The TRACON controller was comfortable with the IM-S AA during OPD operations. The controller noted that IM-S AA during OPDs made operations marginally easier, as aircraft did not have to be sequenced as much and descents did not have to be managed.

Pilots suggested they would have no problem flying IM-S AA on a regular basis and that IM-S AA had no significant impact on their workload. Pilots noticed the IM Speeds quickly and followed them closely. Normal flight crew coordination procedures appeared to be sufficient and display locations were generally acceptable. The IM-S AA initiation method (ACARS data link) appeared to be acceptable and pilots generally felt the CDTI was not required after set-up in order to perform IM-S AA. Flight crews followed appropriate phraseology and it appeared to be sufficient.

In addition, concerns related to logistics were overcome and appropriate data collection methods were developed. This led to a decision to continue with a more extensive, follow-on data collection event in August 2010 which is the subject of this report. The overall activity was sponsored by the SBS Program Office and data collection tools, procedures, and protocols were developed by MITRE, NASA, Johns Hopkins University Applied Physics Lab (JHU APL), and UPS.

1.4 IM Development following the Field Test

After UPS and ACSS fielded their initial implementation of IM-S AA, the concept has continued to evolve. More complex and higher density conceptual implementations are currently being developed to provide ATC with the appropriate tools to use IM-S to achieve their goals. Current program activities also include developing automation support for ATC to perform the ground setup and monitoring (FAA, 2015). The current concept describes the use of IM where aircraft with varying performance capabilities are paired and where ATC is the entity providing the information to initiate IM-S (i.e., the AOC role is greatly reduced), which is in line with much of the pre-UPS implementation research.

Two HITL simulations were conducted at MITRE to examine some of the ground requirements. The first occurred in 2010 and examined a possible, farther-term implementation of GIM with advanced capabilities and interface elements (Benson, Peterson, Orrell, and Penhallegon, 2011). The second was conducted in 2011 and examined a version of GIM closer to the intended functionality for the IOC deployment (Peterson, Penhallegon, and Moertl, 2012). Also during that time, a HITL simulation was conducted examining the use of IM-S during departure operations (Penhallegon, Mendolia, Bone, Orrell, and Stassen, 2011).

IM is currently being defined in terms of operational capabilities supported in the NextGen Bravo and post-Bravo timeframes. The initial set of capabilities is referred to as IM-S Arrival, Approach, and Cruise (AA&C) and is intended to facilitate single runway arrival and miles-in-trail operations. A Concept of Operations (ConOps) for IM-S AA&C has been drafted by the FAA's SBS Program Office describing how ADS-B In avionics and supporting ground systems can be leveraged to enable IM benefits (FAA, 2015). FIM Safety, Performance, and Interoperability Requirements (RTCA, 2015 and EUROCAE, 2015) and Minimum Operational Performance Standards (MOPS) for IM-S AA&C avionics have been published by RTCA Special Committee 186 (SC-186) and EUROCAE Working Group 51 (WG-51). In 2014 the SBS Program Office also began drafting an initial Requirements Document (RD) for ground systems expected to enable IM-S AA&C, such as En Route Automation Modernization (ERAM) and Time-Based Flow Management (TBFM).

As certain air traffic environments may not be able to take advantage of IM due to the limitations of initial avionics and the difficulty of conveying longer initiation clearances via voice, the FAA is currently defining a more complex set of IM operations, referred to as Advanced Interval Management (A-IM), to enable the expected throughput benefits of IM in additional environments. A-IM leverages flight-deck and ground system enhancements to enable single runway IM-S AA&C operations at more facilities, enable IM spacing to multiple runways, and extend the benefits of IM to the departure domain.

A-IM will leverage the Aeronautical Telecommunications Network (ATN) Baseline 2 (B2) data communications capability when possible and may even require it for certain communications, such as conveying complex Target Aircraft Intended Flight Path Information (IFPI) in an initial IM clearance. Simulations such as Bone and Long (2014) and Baxley, Hubbs, Shay, and Karanian (2011) provided input to the definition of the performance requirements for Controller Pilot Data Link Communications (CPDLC) messages. Besides Data Comm, A-IM is also expected to leverage additional capabilities available in the post-2020 timeframe such as TBFM multiple runway scheduling, ATC Winds, and Dynamic Required Navigation Performance (DRNP), to increase the performance and benefits of IM operations. Avionics requirements for A-IM started being defined in 2015 and applications are expected to become available in the 2020 – 2025 timeframe.

2 Test Objectives and Data Collection Methodology

2.1 Test Goals

The overall goal of the 2010 IM Field Test was to demonstrate the viability of the concept for maturing and validating relevant portions of IM-S AA documentation. The test also provided field validation of the application, as well as field data to support standards development and benefits analysis. The specific research objectives were to:

1. Validate IM-S AA concept and procedures and identify potential for improvement.
   - Clear procedures are critical for the acceptability of IM-S AA and results were intended to feed back into concept procedural definition activities. The ATC component only examined those areas where the controller was involved, such as IM Aircraft monitoring. Areas where ATC was not involved, such as issuing the IM-S AA initiation information, were only examined from a GOC / flight crew perspective with the expectation that ATC procedures might be similar.
2. Document the IM-S AA algorithm performance – number/magnitude of IM Speeds, delivery accuracy, etc.
   - Results are important for the determination of benefits expected from IM-S AA as well as for flight crew and controller acceptance and trust in the system and operation. The number of IM Speeds has a strong effect on perceived workload while magnitude of IM Speed changes and IM Speed reversals can lead to distrust of the system. Results were intended to be used as input to algorithm design to achieve air traffic management goals in an operationally acceptable manner.
3. Determine the impact of IM-S AA (benefits or detrimental effects) on current operations and on OPDs.
   - Results were intended to help determine the interactions between IM-S AA and OPD operations and whether changes needed to be made to either to accommodate an operation including both.
4. Determine if the FIM tools and user interfaces are appropriate and acceptable and identify potential for improvement.
   - Results were intended to help determine the necessary information elements and locations. The results can be used in the definition of standards as well as in the design of future displays.
5. Evaluate an initial, limited phraseology set for IM-S AA communications with ATC
   - New phraseology is required for IM-S. Results were intended to help determine appropriate and necessary phraseology for communications.

Some of the metrics that were used to inform the research objectives included spacing and tolerances achievable in the field, crew and controller behavior during actual operations, and user acceptability, performance, and human factors. Most of these metrics were evaluated from the perspective of flight crews and air traffic control (including ZID and ZKC ARTCCs as well as the SDF TRACON).

2.2 Data Collection Sources

2.2.1 Subjective Data Sources

During the test flights, observers from MITRE and NASA were present on the flight decks of the IM-S AA equipped aircraft and collected data via pre-formatted observer forms. Pilots were also asked to fill out a post-flight questionnaire. These materials are provided in Appendix A.

On the ground, observers at ZKC, ZID, SDF TRACON, and the UPS GOC collected data on pre-formatted observer forms (Appendix B). The data collection activity was not constructed to deviate from nominal IM-S AA procedures, nor introduce any new factors other than the presence of observers.

2.2.2 Objective Data Sources

Quantitative data was collected through:

- SafeRoute avionics data captured on board IM-S AA equipped aircraft (off-loaded by UPS and provided by ACSS),
- Flight Operational Quality Assurance (FOQA) and Surface Decision Support System (SDSS) data (provided by UPS), and
- JHU APL ADS-B Out message data.

Each of these sources contained numerous types of data. The specific data elements that were used in the analysis and results are noted in the test matrices in the following section.

2.3 Test Matrices

Based on the test objectives, the primary areas of interest included:

- Operational performance (behavior of the participating aircraft)
- Crew conformance with and acceptability of the IM Speeds
- Procedures validation
- Benefits

The following tables provide detailed research questions and elements of interest at the time of the test, the IM activities requesting the information, and the documents to which the data applied at the time. It also maps the data collection elements and source to each of the questions, as well as where the results for each of the questions can be found in this document. In some cases, the research questions are not necessarily answered as part of the field test data analysis process; instead test data was provided to representatives of the groups for their own analysis. Operational performance questions are provided in

Table 2-1, Crew Conformance / Acceptability questions are provided in

Table 2-2, Procedures Validation questions are provided in Table 2-3, and Benefits questions are provided in Table 2-4.

Table 2-1. Operational Performance

Req #	Description	Requestor	Purpose	Supporting Data Element	Data Source	Results Mapping
OP1	Can aircraft consistently manage their own spacing to a target interval? If so, what tolerances are achievable in actual operations during OPD?	Requirements Focus Group (RFG) FIM	Operational Performance Assessment (OPA) Dev. (Performance Modeling)	In-Trail Time (ITT) spacing values as function of time / location	ACSS / FOQA / APL / Flight Deck Observers	• Section 4.2
		FIM Subgroup (SG)	IM-S Concept of Operations (CONOPS) Maturation			
OP2	How do spacing errors evolve in time?	RFG FIM	OPA Dev. (Performance Modeling)	ITT spacing values as function of time / location	ACSS / FOQA / APL / Flight Deck Observers	• Section 4.2
OP3	How are spacing errors different as a function of the IM-S AA aircraft's position in the chain?	RFG FIM	OPA Dev. (Performance Modeling)	ITT spacing values as function of time / location	ACSS / FOQA / APL / Flight Deck Observers	• Aircraft data available for further analysis as needed.
		FIM SG	IM-S CONOPS Maturation			
OP4	How does threshold spacing vary with spacing at or near the FAF?	RFG FIM	OPA Dev. (Performance Modeling)	ITT spacing values as function of time / location	ACSS / FOQA / APL	• Section 4.3
		FIM SG	IM-S CONOPS Maturation			
OP5	How does the aircraft's vertical trajectory change with the addition of IM Speeds?	RFG FIM	OPA Dev. (Performance Modeling)	Aircraft State Data IM Speed Data	ACSS / FOQA / Flight Deck Observers	• Section 4.9
		FIM SG	IM-S CONOPS Maturation			
OP6	What role do winds play in the operation?	RFG FIM	OPA Dev. (Performance Modeling)	Aircraft State and Wind Data FMS Wind Input	ACSS / Flight Deck Observers	• Aircraft data available for further analysis as needed.
		FIM SG	IM-S CONOPS Maturation			
OP7	Aircraft State Data • Time; LAT/LONG; Pressure Altitude; Indicated Airspeed;	RFG FIM	OPA Analyses	Aircraft State Data	ACSS / FOQA / APL	• Aircraft data available for further

Req #	Description	Requestor	Purpose	Supporting Data Element	Data Source	Results Mapping
	Calibrated Airspeed; True Airspeed; Ground Speed; FMS FAS				Flight Deck Observers (FMS FAS)	analysis as needed.
OP8	IM-S AA Data • ITT; IM Speed in IAS; IM Speed in Groundspeed (calculated speed prior to conversion to CAS); Message related to reception of lead aircraft's ADS-B message; Distance to go; Winds used in the calculation	RFG FIM	OPA Analyses	IM-S AA Data	ACSS / Flight Deck Observers	• Aircraft data available for further analysis as needed.
OP9	Ground Surveillance Data • ADS-B messages from all IM-S AA aircraft, including lead, with timestamp. • Fused surveillance data on all IM-S AA aircraft, including lead, with timestamp.	RFG FIM	OPA Analyses	Ground Surveillance Data	APL	• Ground-tracked ADS-B data available for further analysis as needed.

Table 2-2. Crew Conformance / Acceptability

Req #	Description	Requestor	Purpose	Supporting Data Element	Data Source	Results Mapping
AC1	Aircrew Acceptability of IM-S AA • IM Speed Compliance • IM Speed Magnitude • IM Speed Period	RFG FIM	Operational Service and Environment Description (OSED) / OPA Validation	Aircrew IM-S AA Acceptability	Flight Deck Observers / Pilot Questionnaire	• Section 4.2 • Section 4.4 • Section 4.5 • Section 4.8 • Section 4.10
		FIM SG	IM-S CONOPS Validation			
AC2	Aircrew Conformance with IM Speeds • Crew Response Time • Any special cases, such as acceleration IM Speeds after the crew has started to configure	RFG FIM	OSED / OPA Validation	IM Speed Conformance	ACSS / Flight Deck Observers	• Section 4.2 • Section 4.4 • Section 4.7
		FIM SG	IM-S CONOPS Validation			
		UPS	Concept Implementation			
AC3	ATC Acceptability of IM-S AA	RFG FIM	OSED / OPA Validation	ATC IM-S AA Acceptability	Facility Observers	• Section 4.11
		FIM SG	IM-S CONOPS Validation			

Table 2-3. Procedures Validation

Req #	Description	Requestor	Purpose	Supporting Data Element	Data Source	Results Mapping
PV1	Aircrew IM-S AA Setup Procedures Validation	RFG FIM	OSED / OPA Validation	Aircrew IM-S AA Setup Procedures Acceptability	Flight Deck Observers	• Section 3.7 • Section 4.10.3 • Section 0 • Section 4.10.6
		FIM SG	IM-S CONOPS Validation			
		UPS	Concept Implementation			
PV2	Aircrew IM-S AA Termination Procedures Validation	RFG FIM	OSED / OPA Validation	Aircrew IM-S AA Termination Procedures Acceptability	Flight Deck Observers	• Section 4.10.3 • Section 0
		FIM SG	IM-S CONOPS Validation			
		UPS	Concept Implementation			

PV3	Aircrew Spacing Disruption Procedures Validation	RFG FIM	OSED / OPA Validation	Aircrew IM-S AA Spacing Disruption Procedures Acceptability	Flight Deck Observers	• No spacing disruptions observed during test.
		FIM SG	IM-S CONOPS Validation			
		UPS	Concept Implementation			
PV4	ATC Spacing Disruption Procedures Validation	RFG FIM	OSED / OPA Validation	ATC IM-S AA Acceptability	Facility Observers	• No spacing disruptions observed during test.
		FIM SG	IM-S CONOPS Validation			
PV5	IM-S AA Phraseology Validation	RFG FIM	OSED / OPA Validation	Phraseology Acceptability	Facility and Flight Deck Observers	• Section 0
		FIM SG	IM-S CONOPS Validation			
		UPS	Concept Implementation			

Table 2-4. Benefits

Req #	Description	Request-or	Purpose	Supporting Data Element	Data Source	Results Mapping
BE1	Does IM-S AA reduce ATC interventions up to and after the En Route achieve-by point (including terminal)?	RFG FIM	OSED / OPA Validation	IM-S AA Interventions	Flight Deck and Facility Observers	• As noted in Section 4.11, no ATC interventions were made with any of the IM-S AA aircraft after the operation had begun. However, baseline data was not available to determine any specific differences resulting from the introduction of IM-S AA.
		FIM SG	IM-S CONOPS Validation			

2.4 Data Collection Methodology

The following matrices describe the data collection procedures. Table 2-5 describes aircraft data collection and Table 2-6 describes data collected at ATC facilities.

Table 2-5. Flight Deck Data Collection Methodology

Data	Data Collection Tool	Data Collection Procedure	Organizations Responsible for Data Collection	Organizations Responsible for Data Analysis and Reporting
Aircrew Acceptability / Human Factors	Flight Deck Questionnaire	1) Observers provide forms to aircrews before leaving aircraft 2) Pilots complete them in observer's presence 3) Observers return forms to MITRE and NASA Ames	MITRE NASA Ames NASA Langley	MITRE NASA Ames
Concept / Human Factors Observations	Flight Deck Observer Form	1) Observers complete forms during flight 2) Return completed forms to MITRE and NASA Ames	MITRE NASA Ames NASA Langley	MITRE NASA Ames
Algorithm ITT spacing data	ACSS Smartcard capture JHU APL ADS-B data	1) Cards are installed on aircraft (a/c) through Engineering Order 2) Post-flight, data is uploaded to ACSS 3) ACSS provides ITT data to MITRE 4) Critical fix crossing times collected by JHU APL and/or UPS FOQA; provided to MITRE	ACSS JHU APL	MITRE
Aircraft State Data	FOQA	1) UPS obtains aircraft state data from FOQA	UPS	MITRE
SafeRoute data	ACSS Smartcard capture	1) ACSS maintains all other data captured from on-board cards	ACSS	MITRE

Table 2-6. ATC Data Collection Methodology

Data	Tool	Data Collection Procedure	Organizations Responsible for Data Collection	Organizations Responsible for Data Analysis and Reporting
ATC Acceptability / Human Factors	ATC Observer Form	1) Observers complete forms 2) Return completed forms to MITRE and NASA Ames	MITRE NASA Ames	MITRE NASA Ames
Terminal Spacing and IM-S Performance	TRACON Operations Observer Form	1) SBS TRACON Observer completes form while observing in TRACON 2) Completed forms are sent to MITRE	SBS	MITRE NASA Ames

2.5 SafeRoute Data Availability

Following the test, SafeRoute objective data was unavailable for four of the participating aircraft and not useful for a fifth. The cause is unclear: two data files were corrupted and unidentifiable and the total number of data files was two less than the number of aircraft participating. However, the remaining files were successfully identified. Table 2-7 summarizes the availability of the SafeRoute data by flight.

Table 2-7. On-Board Objective Data Collection Availability Summary

Night	IM-S AA Flight	SafeRoute Data Available?	Comments
1	UPS857	✓	
1	UPS903	✓	
1	UPS905	✓	*Initiation problem; no FIM-S IM Speeds provided*
1	UPS919	✓	
2	UPS857	X	*Data file unusable or card not installed on aircraft*
2	UPS905	✓	
2	UPS903	✓	
2	UPS919	✓	
3	UPS921	X	*Data file unusable or card not installed on aircraft*
3	UPS857	X	*Data file unusable or card not installed on aircraft*
3	UPS903	✓	
3	UPS905	X	*Data file unusable or card not installed on aircraft*
3	UPS919	✓	

3 Test Environment

This section describes the air and ground test environments. These include aircrew and ATC instructions as well as traffic, weather, and other environmental constraints that had bearing on the test. Flight crews used the SafeRoute equipment described in Section 1.3.4 during revenue flights. No ATC automation tools specific to IM-S AA were introduced for this test.

Data collection tools and procedures were vetted through lessons learned from the April 2009 SGT and in reviews with the SBS IM Ad Hoc Industry Group[6] and SBS Program Office leadership. The data collection activity was not constructed or expected to deviate from or add to nominal IM-S AA procedures. The testing was not designed to introduce any new factors, other than the presence of observers. Interviews and surveys were conducted after, not during, the flights. Flight crews were not asked to record any test data or observations during flight and observers were instructed not to interfere with normal operations.

Although the operation was referred to as "Merging and Spacing (M&S)" in the initial implementation and training material, the IM-S AA term has been substituted for the terminology UPS and ATC used in its briefings and instructions. These cases are noted by brackets.

Several organizations were involved in the field test activity. UPS developed and provided the flight crew briefing material presented in this section. Participants from MITRE, NASA, and the SBS program office recorded observations and MITRE compiled and summarized the observations.

3.1 Domain and Operation

Three IM-S AA test events were executed in August 2010. The test nights started in the evening and extended past midnight into the morning hours of the following day (SDF local time). The test nights are referred to as Night 1, Night 2, and Night 3 in this document. UPS management pilots flew the UPS B767 SafeRoute-equipped aircraft as the IM-S AA aircraft. The participating aircraft (including the lead aircraft in a chain of aircraft conducting IM-S AA) arrived via the BRRWN ONE ARRIVAL[7] which is a Continuous Descent Arrival (CDA) (i.e., OPD) to SDF runway 35R (Figure 3-1). The non-IM-S AA aircraft were routed to runway 35L. In this test, the Pocket City (PXV) Very High Frequency (VHF) Omnidirectional Range (VOR) was the OPD entry point and also acted as the merge and achieve-by points. TOD for many of the flights were also at or just after PXV. IM-S AA trail aircraft, on initial contact with each controller, were to announce "COMPANY SPACING."

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[6] At the time of the test, this group was referred to as the FIM Subgroup (FIM SG).

[7] The BIG EAST and BRRWN ONE arrival procedures were developed by and tailored for UPS; they are not available to the public.

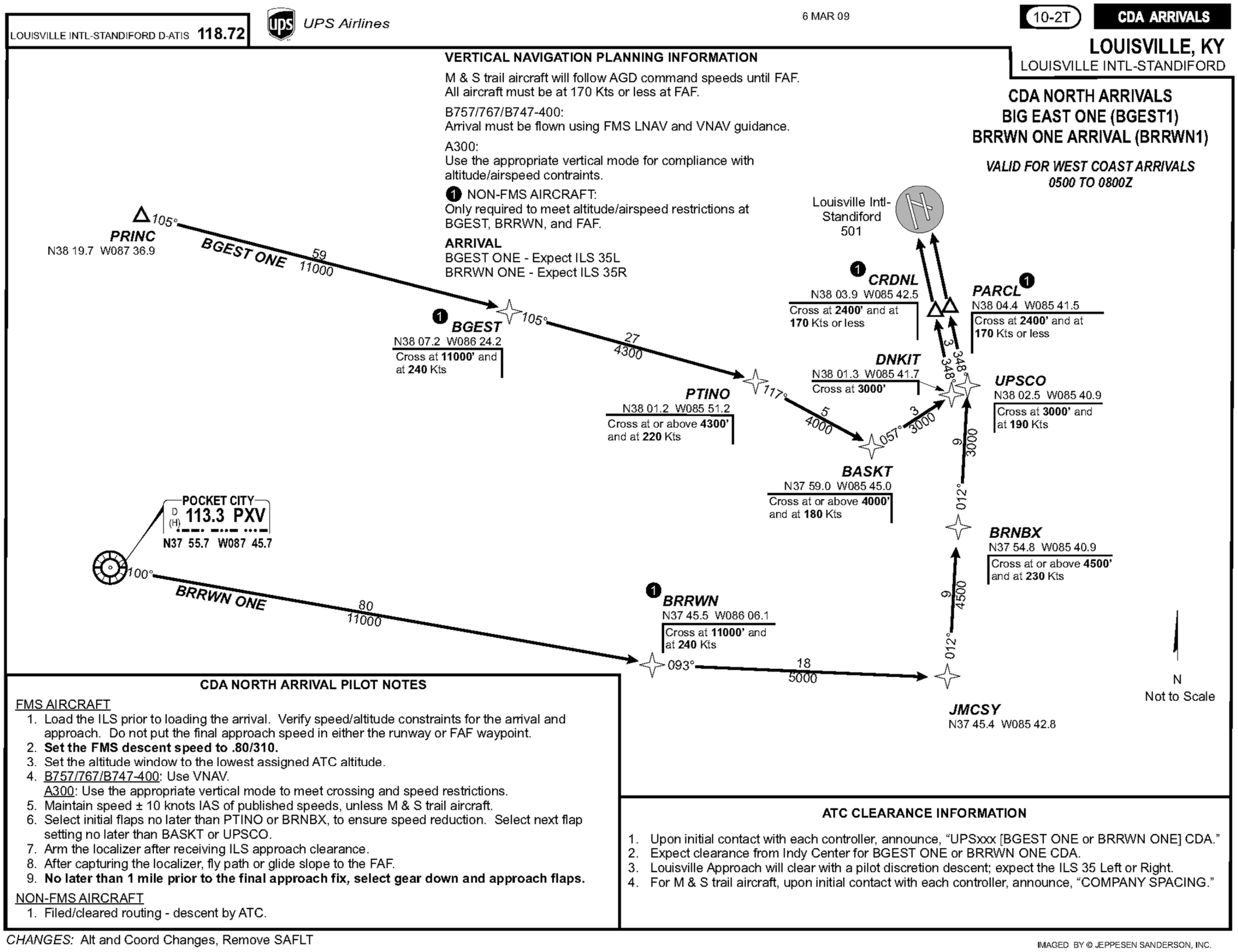


Figure 3-1. UPS OPD for North Arrivals

After PXV, several downstream waypoints contained associated altitude and speed crossing restrictions (SCRs). In the procedure chart, the speed restrictions have a note for FMS aircraft that says “Maintain speed +-10 knots Indicated Air Speed (KIAS) of published speeds, unless [IM-S AA] trail aircraft.” A related IM-S AA note says, IM-S AA “trail aircraft will follow AGD [IM Speeds] until FAF.”

For the test UPS decided to use a time-based interval of 145 seconds, which was intentionally well outside the minimum 4 NM separation required between two 767 aircraft. The ASG was given in time so that it could remain a constant value. However, the distance between the aircraft decreases as the aircraft decelerate for the arrival and approach to landing. Therefore, maintaining 145 seconds resulted in a distance of approximately 20 NM at the start of the OPD, which compressed to a distance of 5.5 to 6 NM on final approach. It was assumed that this ASG was a reasonable initial value that could be reduced to a closer final distance after sufficient operational experience.

Aircraft setup for the flight deck phase was accomplished mostly by managing departure times, the GOC sending the initial sequence to crews via ACARS, and aircrew coordination over company frequency to establish an initial spacing prior to starting IM-S AA (see Section 3.7 for more). It did not involve ATC or the use of a ground tool specifically designed for this purpose. The aircrew/GOC IM-S AA initiation role is not indicative of the operation as described in any of the current IM-S AA documentation. The focus of this document is primarily on the specific implementation that may be part of a broader IM-S AA operation.

No off-nominal situations, such as terminating at a point other than the planned termination point, requesting a re-route, etc. were deliberately introduced. These situations could, however, have occurred naturally as part of the operation and data collection was prepared to capture them.

Besides passive data collection, the test did not introduce any new procedures or implications for the handling of off-nominal situations. In the event of an off-nominal situation, ATC determined how the situation should be resolved, which would simply be the implied termination of IM-S AA through a vector or speed instruction. The flight crew operational response for the Field Test off-nominal conditions was expected to be the same that aircrew would use during non-data collection IM-S AA operations.

The ATC facilities (ZKC, ZID, and Louisville TRACON) were briefed on the purpose and procedures for the test, the aircraft involved, and expected controller responsibilities. Facility managers were in communication with the UPS GOC during the conduct of the test.

3.2 UPS Flight Crew Briefing

The following sections summarize the instructions, procedures, and other information provided by UPS to the UPS pilot participants.

3.2.1 Instructions

Flight crew briefings were customized for each test event /evening and they incorporated lessons learned from the test event from the previous evening. The following information is a compilation of relevant IM-S AA instructions to the crews.

Cruise / In-flight

- (All nights) Maintain filed Mach/speed, altitude and route of flight until advised by Flight Control via ACARS[8]
- (Nights 1 and 2) Planned in-trail spacing at en route [IM-S AA] start is approximately 22-23 NM, once formation is assembled
- (Night 3) Planned en route, in-trail spacing is 22 NM until 300 NM prior to [achieve-by] point (PXV)
- (Night 3) Fly AGD [IM Speeds] within 300 NMs of [achieve-by] point (PXV)

OPD/IM-S AA

- (Nights 1 and 2) Do not conduct [IM-S AA] if convective weather over [achieve-by] point
- (All Nights) Advise each new sector on check-in that aircraft is “company spacing”
- (Nights 2 and 3) Advise ATC if you need to terminate [IM-S AA]
- (All Nights) Comply with [OPD] pilot’s notes
  - (Night 3) Fly no faster than published [OPD] speeds to ensure a stabilized approach even if AGD commands a faster speed[9]
  - (Night 3) When cleared for ILS RWY 35R approach, maintain 4,000’ until established and comply with [IM Speeds]

Note that the instruction to not fly faster than published OPD speeds, even if IM Speeds are faster, appears to contradict the instruction in the BRRWN One Arrival which states that the IM-S AA aircraft “will follow [IM Speeds] until the FAF.”

[8] Despite this instruction in the briefing, crews manually adjusted speeds to set up the initial spacing (see Section 3.7).

[9] Although this was told to pilots each night, this statement was specifically added to the briefing for Night 3.

3.2.2 UPS IM-S AA Procedures

Table 3-1 lists selected procedures from the UPS Flight Crew IM-S AA Procedures Checklist.

Table 3-1. Selected Procedures from the UPS Flight Crew IM-S AA Procedures Checklist

Checklist Item	UPS Procedure
[IM-S AA] Status	• Check the [IM-S AA] Limitations (Inoperative Equipment) list to ensure the necessary equipment is operational prior to commencing [IM-S AA] arrivals.
[Target Aircraft] Information	• Obtain [Target Aircraft] information of the Flight ID, the [achieve-by] point, and the [ASG] in seconds via ACARS
[IM-S AA] Setup	• Push the M&S key on the CDTI • Enter the Flight ID of the [Target Aircraft], the [achieve-by] waypoint, the [ASG], the final approach speed, and verify range alert is set to 3.0 NM. • Select the COMPLETE button to arm [IM-S AA] • The AGD displaying [an IM Speed] and a distance is the indication that [IM-S AA] has engaged
Lateral Navigation (LNAV)/Vertical Navigation (VNAV), Speed Intervene	• Verify LNAV/VNAV is engaged with speed intervene. Use thrust or speed brakes as required to stay on path[10]
AGD	• Pilot Monitoring (PM) callout any airspeed changes on the AGD • Comply with all [IM Speeds] • Fly no faster than the published [OPD] speeds to ensure a stabilized approach even if AGD commands a faster speed
ATC	• Advise each new sector on check-in that aircraft is “company spacing” • Example: “Kansas City Center, UPS 917, FL350, company spacing” • Also advise ATC if you need to terminate [IM-S AA] • Example: “Kansas City Center, UPS 917, terminating company spacing”

[10] This guidance suggests that once the descent began, aircraft used pitch to control airspeed.

3.2.3 Restrictions

The following are operational restrictions that UPS provided to flight crews:

1. [IM-S AA] can only be performed when advised via ACARS or from ATC[11], with an aircraft Flight ID to follow, and the [ASG].
2. [IM-S AA] can only be performed with [an IM Speed] being displayed on the AGD.
3. [IM-S AA] will be terminated if ATC gives you vectors during the arrival.
4. Crews can resume [IM-S AA] if outside the [achieve-by] point and ATC discontinues vectoring.
5. If there is a discrepancy between the AGD and CDTI information, terminate [IM-S AA].
6. Once flaps are extended, DO NOT increase airspeed to satisfy AGD [IM Speeds]; this will prevent flap overspeeds.

3.2.4 Alternate IM-S AA Operations

UPS provided the following procedures to flight crews in the event of ATC interventions during IM-S AA operations.

1. Descent restricted during [IM-S AA].
   - Attempt to regain path while following [IM-S AA] [IM Speeds]
   - Advise ATC if unable to regain the arrival speed and altitude constraints
2. ATC vectors aircraft off of arrival routing.
   - [IM Speeds] will be invalid until aircraft is returned to arrival routing

[11] Despite this statement being in the crew briefing, the initial UPS implementation was not designed for ATC initiation of IM-S AA.

3.2.5 Equipment Failures/Malfunctions Pilot Actions during IM-S AA

The actions UPS flight crews were instructed to take in the event of equipment problems are provided in Table 3-2.

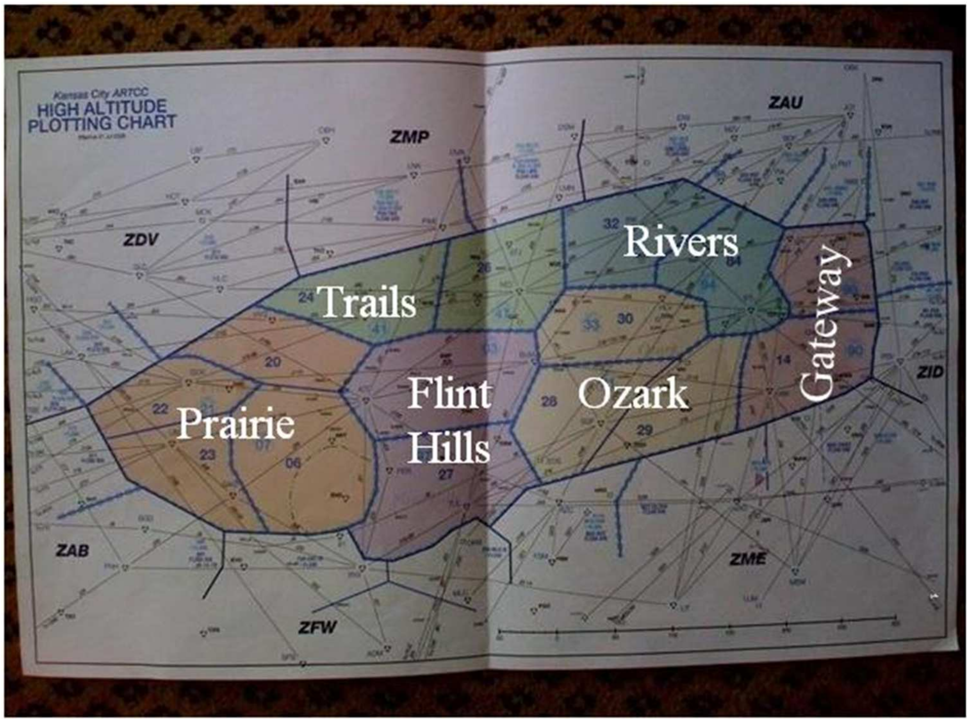
Table 3-2. Equipment Failures/Malfunctions Pilot Actions during IM-S AA

CONDITION	FAILURE/WARNING	ACTION
Autothrottle disconnect	Master Caution Autothrottle DISC light and beeper	Attempt to re-engage autothrottles. If unable, terminate [IM-S AA]
Autopilot disconnect	Master Warning Autopilot DISC light/siren	Attempt to re-engage an autopilot. One autopilot is required to be engaged for [IM-S AA]. If unable to re-engage an A/P, terminate [IM-S AA]
AGD inoperative	N/A	Terminate [IM-S AA]
[IM-S AA] disengages (no [IM Speeds] on the AGD)	[IM-S AA] DISENGAGE message in EFB scratchpad	If outside the merge point, attempt to reengage. If inside the merge point, terminate [IM-S AA]
One or both EFB CDTIs inoperative	N/A	Terminate [IM-S AA]
Discrepancy between AGD and CDTI	N/A	Terminate [IM-S AA]
Target degrades	TARGET DEGRADE message	If target returns to a chevron and outside the merge point, attempt to reengage. If inside the merge point, terminate [IM-S AA]

3.3 Kansas City Center Conditions

3.3.1 Airspace

ZKC airspace was divided into six areas: Prairie, Trails, Flint Hills, Ozark, Rivers, and Gateway (see Figure 3-2). All or most high altitude sectors within each area were aggregated during data collection activities into single control sectors, which is the normal configuration for that time of day. The traffic typically entered in Prairie, then traversed Flint Hills, Ozark, and Gateway. In Prairie, there were three separate high altitude sectors. In Flint Hills, Ozark, and Gateway all high altitude sectors were combined.



FAA / adapted by MITRE

Figure 3-2. Kansas City Center Airspace Areas

3.3.2 Facility Preparation and Observers

The Traffic Management Unit (TMU) supervisor and controllers had printed information about the test, including the list of the test aircraft. This information included the following:

- UPS will conduct [OPDs] using onboard [FIM] equipment on tonight's mid. They plan on using five aircraft towards the end of the SDF arrival push. (The specific aircraft and departure cities were then listed in the material.)
- These aircraft will file (PXV BRRWN1 SDF); and UPS has requested that we do not reroute them nor adjust their speeds unless it is an operational requirement. They will use [IM-S AA] data and upload speed adjustments to the cockpit to achieve 20-22 NM spacing over PXV.
- If a pilot has received a speed adjustment through UPS, they should state "company spacing" on initial contact with each sector. They should also have "MS BRRWN CDA" in the remarks section of the flight plan.

IM-S AA operations were announced throughout the center on a shared situation awareness display and the announcement was repeated throughout the center to all controllers.

Test observers coordinated observation of the IM-S AA test with the TMU and observed IM-S AA and non-IM-S AA aircraft at various ATC sectors. In all sectors only a Radar-side was working; there were no Data-sides. As IM-S AA aircraft transitioned between airspace sectors, the observer visited the corresponding sector positions to listen to the audio and view the aircraft radar returns.

Observations were conducted between approximately 0400 and 0600 Coordinated Universal Time (UTC).

3.3.3 Traffic and Weather

On Nights 1 and 3, traffic density was reported as light-to-moderate (approximately 10 -12 aircraft or less per sector) and there were no traffic flow restrictions or modifications. Traffic density was rated as "moderate" for Night 2, except for the Flint Hills area which managed approximately 20 flights. The observer reported this sector as "quite busy".

Detailed weather data was not collected, but the effect of weather for each night consisted of the following (none of which had a notable impact on the IM-S AA operation):

- Night 1: UPS aircraft re-routed around weather cell to the west of ZKC
- Night 2: Weather cell north of path of test aircraft
- Night 3: Storm cell in the eastern portion of the center forced aircraft to enter center airspace from the north.

3.4 Indianapolis Center Conditions

3.4.1 Airspace

IM-S AA traffic passed through a single ZID area. High and low sectors were aggregated during data collection activities into a single control sector, which is the normal configuration for that time of day.

3.4.2 Facility Preparation and Observers

ZID preparation by controllers and supervisors for the field test included:

- Briefing paper available at the combined sector
- Observers available to answer questions prior to the test
- UPS-provided flight numbers of participating aircraft, posted in the expected arrival sequence
- On Night 3, the observer noted that the Video Status Board in the relevant area through which the IM-S AA traffic passed contained the following message: "SIGNIFICANT INFO: 0200 – 0600 UPS ABESS[12] INTO SDF ON FLIGHTS OVER PXV. ABESS IS AIRLINE BASED

[12] Although an AOC-based setup tool called Airline Based En route Sequencing and Spacing (ABESS) was prototyped to facilitate the UPS operation, it was not actually used during the test. The use of the term ABESS to mean IM-S

ENROUTE SPACING AND SEQUENCING. UPS WILL SEND MESSAGES ELECTRONICALLY TO MANAGE SPEED AND CREATE SPACING. PLEASE LEAVE UPS FLIGHTS ON FILED ROUTE. THE PROGRAM SUCCESS IS BASED ON THE FILED ROUTES." The observers did not note whether this message was also present on Nights 1 and 2.

Test observers watched IM-S AA and non-IM-S AA aircraft as they passed through ZID to the TRACON. As the IM-S AA aircraft transitioned the area, the observer was able to listen to the audio and view the radar display. Only one controller per night managed the IM-S AA traffic.

Observations were conducted between approximately 0530 and 0600 UTC.

3.4.3 Traffic and Weather

The IM-S AA flights were established and remained in a single stream inbound to PXV and directed to the BRRWN arrival route to SDF. Inbound non-IM-S AA flights were vectored in the vicinity of CHERI (north of IM-S AA flights) and directed to the BGEST1 arrival route. Non-IM-S AA flights were spaced at 10 -12 NMs entering ZID Sector, which was described as a typical spacing goal. These flights then typically were spaced at 7 – 10 NMs in trail when transitioned to SDF TRACON.

Traffic density was described by the observers as a "moderate" to "very light." Night 1 consisted of moderate traffic at onset of IM-S AA Flights (10 – 12 aircraft), but IM-S AA flights were at the "tail-end" of UPS west coast arrivals, so traffic transitioned to very light at end of IM-S AA (5 – 7 aircraft). Night 2 consisted of moderate traffic at onset of IM-S AA Flights (13 – 14 aircraft), but traffic transitioned to very light at end of IM-S AA (6 – 7 aircraft). Night 3 also had moderate traffic at onset of IM-S AA flights (12 – 14 aircraft), but very light traffic at end of IM-S AA (6 – 7 aircraft). No special conditions or constraints were observed over any of the three nights.

ZID observer notes for weather and winds were particularly detailed, and reported that each night consisted of the following conditions, none of which had a notable impact on the IM-S AA operation:

- Night 1: Visibility 10 NM; Visual Meteorological Conditions with few clouds at 6000 ft.; winds 20 kts at Flight Level (FL)270 and 50 kts at FL350
- Night 2: Visibility 9 NM; isolated thunderstorms, none affecting UPS flights; tops FL540, patchy light chop FL 350-410; winds 3 kts at 11000 ft., 12 kts at FL230, and 20 kts at FL350
- Night 3: Visibility 10 NM; Cirrus layers/tops to FL390; winds 11 kts at 11,000 ft.; 19 kts at FL230; and 28 kts at FL350

on the ZID Video Status Board highlighted an issue with terminology confusion. See Section 3.7 for more on the setup procedures.

3.5 Louisville TRACON Conditions

The Louisville TRACON airspace was combined into a single sector during data collection activities, which is the normal configuration for that time of day. IM-S AA aircraft merged at PXV, proceeded on BRRWN One, and landed on runway 35R. Non-IM-S AA aircraft arrived on BGEST route and landed on runway 35L. The tower was not part of the test since IM-S was over by the time the aircraft transitioned. The arrival procedure used for the test was provided in Figure 3-1.

3.5.1 Facility Preparation and Observers

The UPS GOC sent the Louisville TRACON a list of UPS flights that would be performing OPDs, with the predicted arrival sequence. The UPS dispatch supervisor called the TRACON facility to inform them about IM-S AA flights.

Observations were conducted starting at approximately 0430 UTC.

3.5.2 Traffic and Weather

IM-S AA aircraft were the last set of aircraft coming from the southwestern quadrant. A small stream (3 – 5) more aircraft landing on runway 35L came from the northwest quadrant. Traffic density was reported to be moderate traffic on all three nights (according to the observers, not more than 10 at a time on Night 1 and 12 – 15 at a time for Nights 2 and 3). The IM-S AA aircraft were directed to use the BRRWN arrival route to land on runway 35R. The localizer for 35R was not functioning on Night 1, but this did not appear to affect the test.

The weather and winds for each night consisted of the following conditions, none of which had a notable impact on the IM-S AA operation:

- Night 1: Good weather
- Night 2: Visibility 9 NM; few clouds at 1500ft; scattered layer at 20,000 ft, calm winds
- Night 3: Visibility 9 NM; few clouds at 4600 ft; winds from 020 degrees at 5 kts

3.6 Participants

Nineteen pilots participated in the evaluation. All were UPS management pilots; most had only limited prior line flights with IM-S AA. Their training primarily consisted of a computer-based training course, a checkride, and a field test training briefing. Some pilots participated on more than one night.

The number of controllers involved in the test varied by facility. Since aircraft transitioned several ZKC areas during the IM-S AA period, the number of controllers observed varied. The exact number was not recorded, but it is estimated at approximately 5 or 6 (2 - 3 for Prairie, 1 each for the Flint Hills, Ozark, and Gateway areas) per night. It is likely that only one controller per facility per night managed the flow at ZID and Louisville TRACON area as operations were combined into single sectors during the IM-S AA period. Observers did not record names so it is unclear how many individual controllers handled the IM-S AA traffic across the events.

3.7 Initial Aircraft Positioning

Initial positioning did not involve ATC or the use of a ground tool specifically designed for this purpose. Aircraft setup began when UPS set departure times for participating IM-S AA aircraft to maximize their chances of getting Target Aircraft within range as quickly as possible. The setup goal was to establish 22 NM[13] initial spacing en route as early as practicable. IM-S AA was not used as part of the initial spacing setup, although IM-S AA initiation messages with expected Target Aircraft were sent to aircraft via ACARS soon after Top of Climb (TOC). Using the CDTI and range readout on the AGD, crews coordinated manually[14] over their company voice frequency to adjust speed to achieve and maintain 22 NM in trail spacing behind the designated Target Aircraft.

The process of getting IM Aircraft into position behind a Target Aircraft at the appropriate spacing to start the OPD proved to be challenging for flight crews. This is not typically a flight crew task, nor should it be, but was done for this field test so the setup would be relatively transparent to ATC. These aircrew / GOC IM-S AA initiation procedures are not indicative of the current IM-S AA concept, in which ATC has the responsibility for set up and initiation.

Aircraft then merged to form chains in Albuquerque Center (ZAB) airspace and typically achieved their 22 NM in-trail initial spacing goal soon after. Crews maintained their spacing manually until approximately 300 – 400 NM from the merge / achieve-by point (PXV). At this range, they began following the IM Speeds to achieve the ASG.

The initial positioning method created some ambiguities for the flight crew in determining exactly where IM-S AA was intended to start and how active they would be in managing the spacing, as opposed to just following the IM Speeds. Some crews thought they should receive IM Speed changes after initiating the FIM equipment early on, soon after TOC. Due to inconsistent setup methods (sometimes PXV was input at this time, sometimes not), IM Speeds could be displayed but appeared incorrect (i.e., a speed-up was displayed when this would have led to spacing that the flight crew judged to be too close).

The artificial setup process also seemed to cause some interference with the IM-S AA tasks. For example, on Night 3 the flight crew on UPS919 was flying at reduced speed during the setup period, waiting for UPS905 to "catch up" with its lead UPS903. The first IM Speed contradicted this strategy in that it instructed the crew to speed up. The IM Speed was therefore not selected

[13] UPS chose 22 miles as the initial spacing goal; however, it was unclear how this specific value was derived.

[14] Although the ABESS AOC-based setup tool was prototyped to facilitate the UPS operation, development was discontinued as the responsibility for IM-S AA setup was allocated to ATC. A description of the ABESS tool and results from several field trials can be found in Moertl and Pollack, 2011. Operations with more complexity and greater levels of equipage would likely use a ground system for initial setup.

because it would have “disturbed” their IM-S AA setup strategy. Such difficulties point to the need for the appropriate ATC ground operations and capabilities for the set-up and initiation of IM-S AA.

In order to provide a consistent period of operation, this report considers the start of the IM-S AA period to be when each IM-S AA aircraft crossed inside a 300-NM (along-track) range to the achieve-by point (i.e., PXV). This is consistent with ACSS’s system specification, which noted that the SafeRoute equipment suppresses IM Speeds until the aircraft is within 300 NM of the achieve-by point[15].

[15] Despite this, it was observed during the test that IM Speeds were on occasion provided to aircrews outside of the 300 NM range.

4 Results

The following sections present the subjective and objective results for each of the test events with regard to spacing performance, IM Speed compliance and conformance, operational impact, and concept acceptability and human factors. Narratives that summarize the observations made at the ATC facilities are also included. See Appendix C for flight progressions during each test event.

Subjective results are based primarily on data collected from pilot questionnaires and from flight deck and ATC observer forms. MITRE, NASA Ames, and representatives from the SBS Program Office recorded the observational data. The questionnaire provided to pilots is included in Appendix A. The forms provided to ATC facility observers are included in Appendix B. Much of the narratives and objective analyses are based on the results as presented in the operational timelines provided in Appendix D. These timelines were compiled from several data sources: ACSS and UPS provided SafeRoute[16] and FOQA data, MITRE, NASA, and SBS observational data, JHU / APL provided aircraft position report data (used to calibrate fix crossing times), and UPS and SBS observers provided final spacing data as noted. As shown in Table 2-7, SafeRoute data was unavailable for four of the flights. In these cases, IM Speed and other data was derived from observer notes. UPS905 from Night 1 is not included in most of the analyses as an equipment setup error prevented the display of IM Speeds to crews. However, crew comments are included in the subjective results when relevant. MITRE analyzed the data and summarized the results.

4.1 Analysis Methodology

4.1.1 IM Speed Compliance vs. Conformance

IM Speed *compliance* is defined by the crew Selected Speed input (SEL) on the MCP following a change in IM Speed. Flight crew reactions to IM Speeds were classified into three categories: Selected, Already Selected, and Not Selected. These are defined as:

- *Selected* IM Speeds are those in which the crew responded with a SEL value exactly matching the IM Speed.
- *Already Selected* IM Speeds are situations in which the crew had previously input a SEL speed that was different from the IM Speed. Following this, the IM Speed changed to match the already set SEL value. In these cases, the crew did not need to take further action to comply with the IM Speed.

[16] SafeRoute speed data is reported in Mach and CAS. Based on consultations with ACSS, the difference between CAS and IAS for these flights is negligible. Thus, for simplicity, this report uses Mach and IAS (and KIAS) as the airspeed units.

- *Not Selected* IM Speeds are those in which the crew either responded with a different Selected Speed (SEL) value or made no input.

IM Speed compliance, however, does not fully capture how well a flight conformed to the overall IM Speeds over the IM-S AA period. Although crews may have initially selected IM Speeds, the overall IM operation is not as simple as following IM Speeds exactly and instantaneously. Many factors play into the decision such as procedural speeds, configuration needs, etc. These factors led crews to adjust SEL independent of the IM Speed value. To account for these crew-initiated speed changes, the *conformance* to the IM Speed throughout the IM-S AA period was also examined. Conformance is defined here as the degree to which the SEL speed matched the IM Speed over the IM-S AA period. However, at times crew may have managed actual aircraft speed through means other than SEL. Only one instance of this was observed and is accounted for in the results. As such, SEL provides a reasonable overall indication of crew intent to conform to the IM Speeds.

SafeRoute data and observer reports were used to determine the percentage of time SEL (Mach and KIAS) on the MCP was in conformance with the IM Speed. The example in Figure 4-1 provides an explanation for the IM Speed conformance graphics. Although the example is for KIAS conformance, Mach conformance results figures in the Achieve Phase should be interpreted the same way.

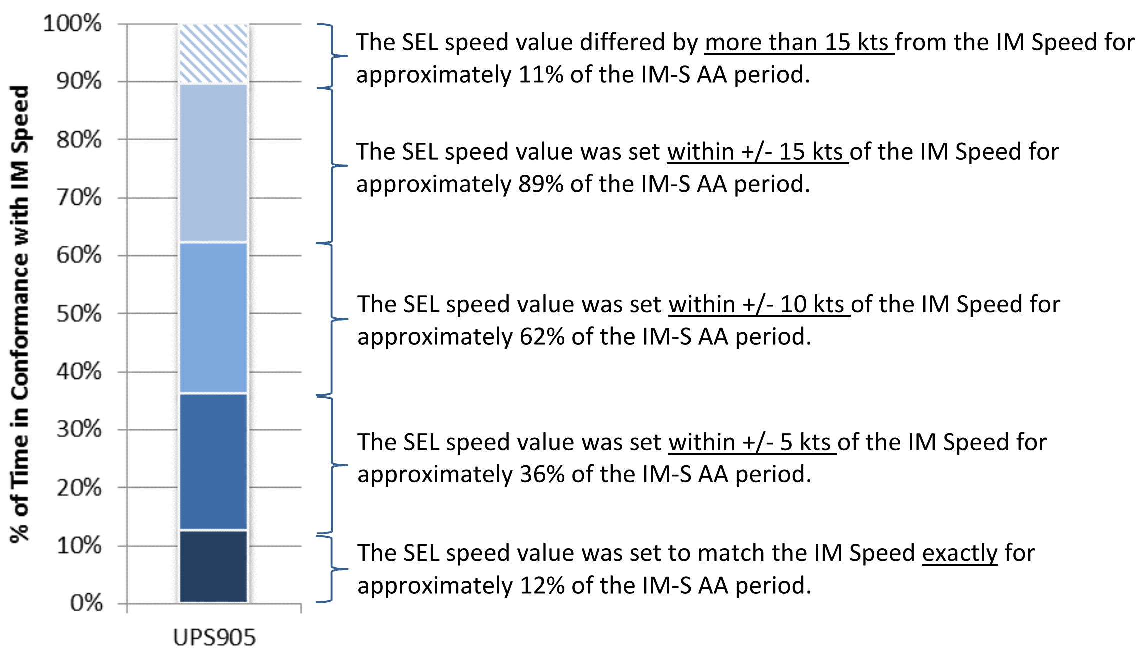


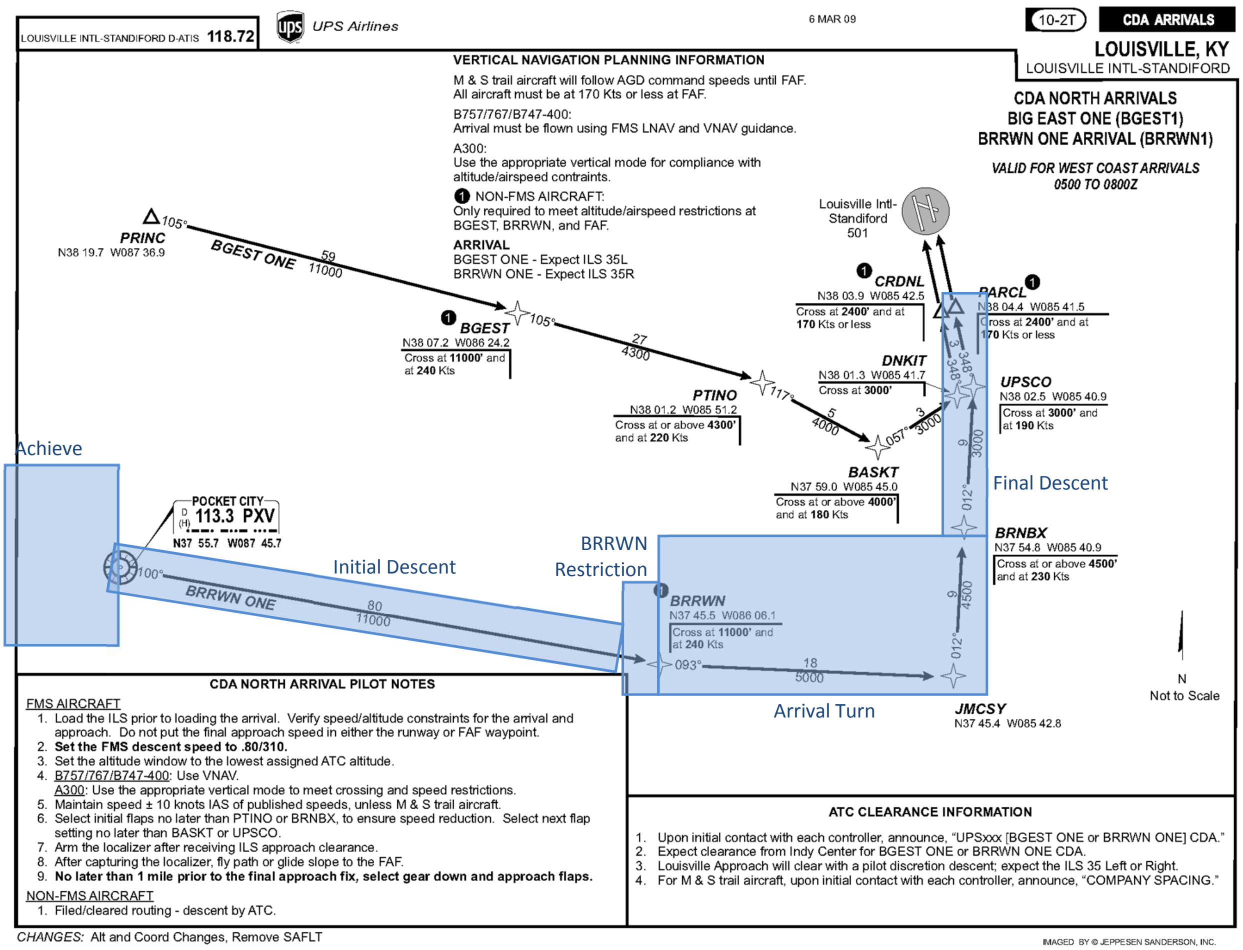
Figure 4-1. Explanation for IM Speed Conformance Figures

Compliance and conformance were determined by crew response to the IM Speed and the following quantitative results are based on SEL response alone. However, actual aircraft speeds in at least once case suggested higher conformance, or intent to conform, than SEL conformance. This occurrence is noted and discussed when relevant.

4.1.2 Flight Phase Descriptions

This section considers results for both the Achieve and whole Maintain periods. For some analyses, the Maintain Phase was divided into four sub-phases for the BRRWN ONE CDA arrival. Each of the phases are plotted against the arrival in Figure 4-2 and include:

1. *Achieve*: The period between the start if the IM-S AA period and the achieve-by point (PXV). Although most flights flew Mach speeds before TOD, some flights transitioned early to KIAS.
2. *Maintain - Initial Descent*: The period after the achieve-by point but before the deceleration leading into BRRWN. This phase ended for each flight when *either* an IM Speed that was less than 300 KIAS appeared, *or* the crew initiated a SEL speed change that was less than 300 KIAS – whichever came first.
3. *Maintain - BRRWN Restriction*: The period between the end of the Initial Descent as defined above and just before the BRRWN fix.
4. *Maintain - Arrival Turn*: The period that started as the aircraft crossed BRRWN and ended just before BRNBX. This period included the turn at JMCSY.
5. *Maintain - Final Descent*: The final speed reduction period that included the speed restrictions at BRNBX and UPSCO. This period ended when the Target Aircraft touched down (TGT TD).



Arrival Plate Courtesy of UPS; modified by MIITRE

Figure 4-2. Maintain Arrival Phases

4.2 Flight Summaries

This section provides an overview for each of the test nights, IM Speed conformance and compliance by phase, and narratives of crew actions and aircraft spacing performance summaries for each of the flights. The summaries generally consist of a narrative, speed profile plots, conformance figures, and spacing performance plots.

The speed profile plots show the IM Speed, SEL, and actual aircraft speed profiles relative to UTC per flight over the IM-S AA period (300 NM from PXV to TGT TD). Most include Mach and KIAS components, although some flights stayed in KIAS for the duration of the IM-S AA period. The Mach/KIAS crossover typically occurred within a few minutes after crossing PXV.

Most figures are sourced from SafeRoute data sampled every second. When SafeRoute data was not available, the speed values are based on observer notes recorded by NASA Ames and MITRE. As observer notes are not as precise as the SafeRoute on-board data collection, the results for these flights are coarser as compared to those with successful on-board data collection. However, the non-SafeRoute flight profiles still provide a rough indication of how IM Speed values related to aircraft SEL and actual KIAS. On Night 2, this method was used for UPS857. On Night 3, this method was used for UPS921, UPS857, and UPS905. In these cases, with the exception of UPS921, actual speed data was available from the trailing IM Aircraft's SafeRoute data. As noted earlier, data from UPS905 on Night 1 is not included as an equipment setup error prevented the display of IM Speed to crews.

The narratives discuss the IM Speed and SEL changes and provide rationale for non-compliance and non-conformance when it could be determined from the data or observer notes. Conformance for each phase was categorized as high, medium, or low per the following:

- IM Speed conformance is defined as "high" if the SEL speed was within M0.01 or 5 kts of the IM Speed at least 80% of the phase.
- Conformance is defined as "medium" if SEL was within M0.02 or 10 kts of the IM Speed at least 50% of the phase.
- Conformance is also defined as "high" or "medium" if it could be determined from the actual speed data that crews were attempting to comply with the IM Speeds through means other than SEL. Only one case was observed and is discussed in the narrative.
- Conformance is otherwise defined as "low."

Occasionally conformance categorizations were made that did not strictly meet the above definitions. Rationales for the deviations in these rare cases are discussed in the narrative.

For flights with SafeRoute data available, tables are also provided that summarize aircraft conformance with IM Speeds, based on SEL and actual aircraft speed when appropriate. The tables include the Achieve Phase and the four Maintain sub-phases. The tables also provide the overall spacing performance and final spacings when each IM Aircraft's Target Aircraft touched down. Spacing performance results were obtained from the SafeRoute data per the following:

- The achieve-by point time spacings were taken when the IM Aircraft crossed PXV.
- The Maintain spacing values comprise the range of spacing values between the achieve-by point and TGT TD.
- Final spacing values were not specifically identified as such in the SafeRoute data. For this analysis, an IM Aircraft's final spacing is the algorithm spacing value just before its Target Aircraft's pressure altitude became constant. This defined the TGT TD point referred to in this report. Given the spacing interval in use, the IM Aircraft was approximately at its termination point when the Target Aircraft touched down. Therefore, the Final Spacing values approximate the spacing at IM-S AA termination.

The narratives also describe cases of IM Speed trend changes, which are the number of times the IM Speed (Mach and KIAS) changed from speed up / slow down to slow down / speed up per flight relative to the previous IM Speed value at the time of the change. Detailed analysis of the trend changes is provided in Section 4.6.

The flight summary sections also include spacing performance plots, which present algorithm spacing interval data (time and distance) as collected by the SafeRoute on-board equipment when available. The data was sampled every 15 seconds. The PXV crossing times were determined from the SafeRoute data while other fix crossing times are based on ADS-B position reports provided by JHU APL and are included on the charts. The 145 second (sec) ASG used during the test are shown in the figures as a dotted line, though this is really only relevant at the achieve-by point and during the Maintain Phase.

The plots also include the IM Speeds and flight crew-initiated speed changes. Speeds are shown in kts, unless otherwise noted as Mach (M). The coding used for each speed is summarized in Table 4-1. Sections 4.4 and 4.5 provide more detailed IM Speed analyses.

Table 4-1. Spacing Performance Figure Legend

Symbol	Description
IM-SEL	(IM – Selected) An IM Speed appeared and the crew selected it by adjusting SEL to match the IM Speed value exactly.
IM-AS	(IM – Already Selected) An IM Speed appeared that matched the current SEL value. (No crew action was necessary to comply.)
IM-NS	(IM – Not Selected) An IM Speed appeared and was not selected by either entering a different SEL value or ignoring completely.
FC-INI	(Flight Crew – Initiated) A flight crew-initiated speed change. These could either be a different SEL response to an IM Speed that was not selected, or a speed change that occurs between successive IM Speeds.
↑	Speeds shown below the time spacing line with an up arrow indicate that the speed is having the effect of increasing spacing and visually “pushing” the time spacing line upwards toward the ASG (with a slower speed).
↓	Speeds shown below the time spacing line with a down arrow indicate that the speed is having the effect of reducing spacing and visually “pushing” the time spacing line downwards toward the ASG (with a faster speed).

Note: The following individual flight summaries provide the detailed foundation and rationale for findings in subsequent sections. Readers more interested in results summaries across the flights may wish to resume reading with Section 4.3.

4.2.1 Night 1 Sequence

Departure times were calculated and instituted by UPS to provide the best chance of successful airborne IM-S AA pairings. The aircraft departure sequence is shown in Table 4-2.

Table 4-2. Night 1 Aircraft Departure Sequence

Flight ID	Departure Gateway and Wheels Up Time (UTC)
UPS903	LAX at 0231
UPS905	LGB at 0240
UPS919	ONT at 0245
UPS857	PHX at 0303

Once in the air, initial setup was performed as described previously. Figure 4-3 shows the final aircraft sequence. Spacing pairs are shown with IM Aircraft to the left of an overall lead aircraft (the rightmost aircraft is the first in the chain). The light-colored arrow indicates that IM-S AA was not initialized properly for UPS905, so this aircraft did not perform IM-S AA (see Section 4.10.6 for a discussion). As such, the result was a chain of three aircraft followed by a pair.

UPS919 → UPS905 → UPS903 → UPS857 → UPS921

Figure 4-3. Night 1 Final Aircraft Sequence

All IM-S AA aircraft arrived and landed on 35R at SDF via the BRWWN CDA without ATC intervention. A graphic representation of the flight progression is provided in Appendix C.

4.2.2 UPS857 Night 1 Flight Summary

Profiles of IM, Selected, and Actual Mach Speeds for UPS857 during the IM-S AA Achieve Phase are summarized in Figure 4-4. UPS857 entered the phase slightly outside the ASG and flying the IM Speed. Approximately 22 minutes in, the crew increased speed to M0.80 in response to an announcement by its Target Aircraft that it would be flying M0.80. Flying that speed led to passing through the ASG and the flight crew then reduced the SEL to M0.78. Not long after, the IM Speed value changed to 0.79 and the crew responded after approximately a five-minute delay, which was the only occurrence where the flight crew took longer than 60 seconds to comply with the IM Speed. Outside of this period, MCP Selected Speed and aircraft Actual Speed were within M0.02 of the IM Speed. Spacing at the achieve-by point was only 4 seconds outside of the ASG.

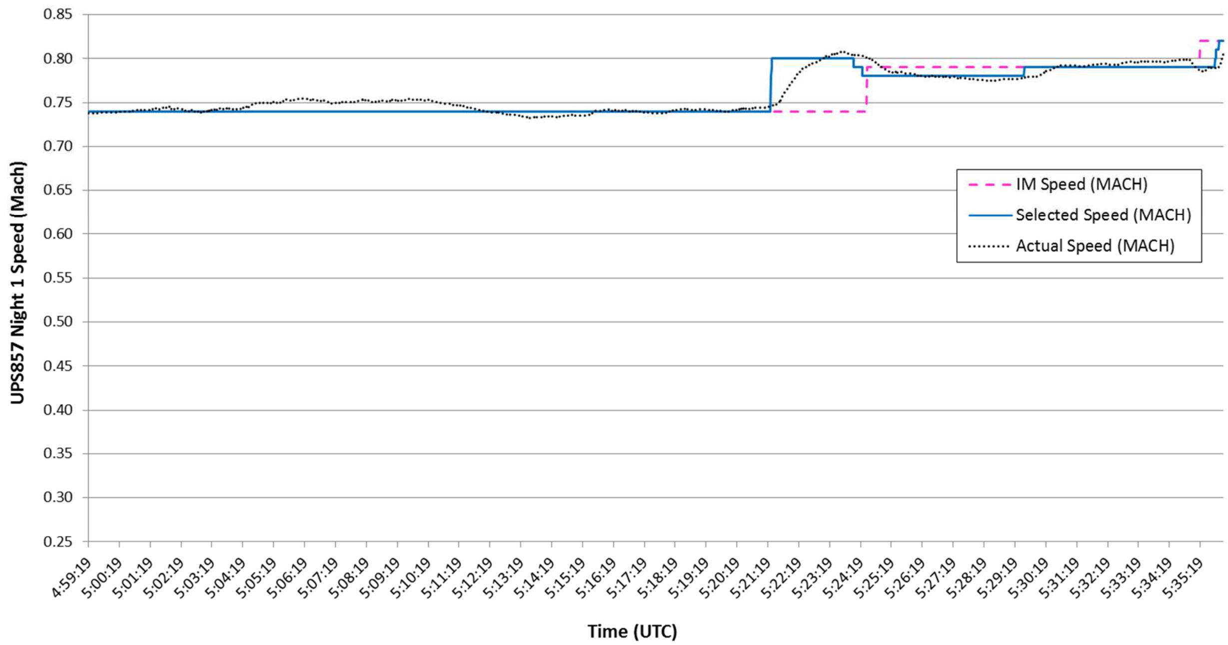


Figure 4-4. Night 1 UPS857 Speed Profile (MACH)

Profiles of IM, Selected, and Actual KIAS Speeds during the descent and arrival are shown in Figure 4-5. The percent of time the SEL was in conformance with the IM Speed during this period is shown in

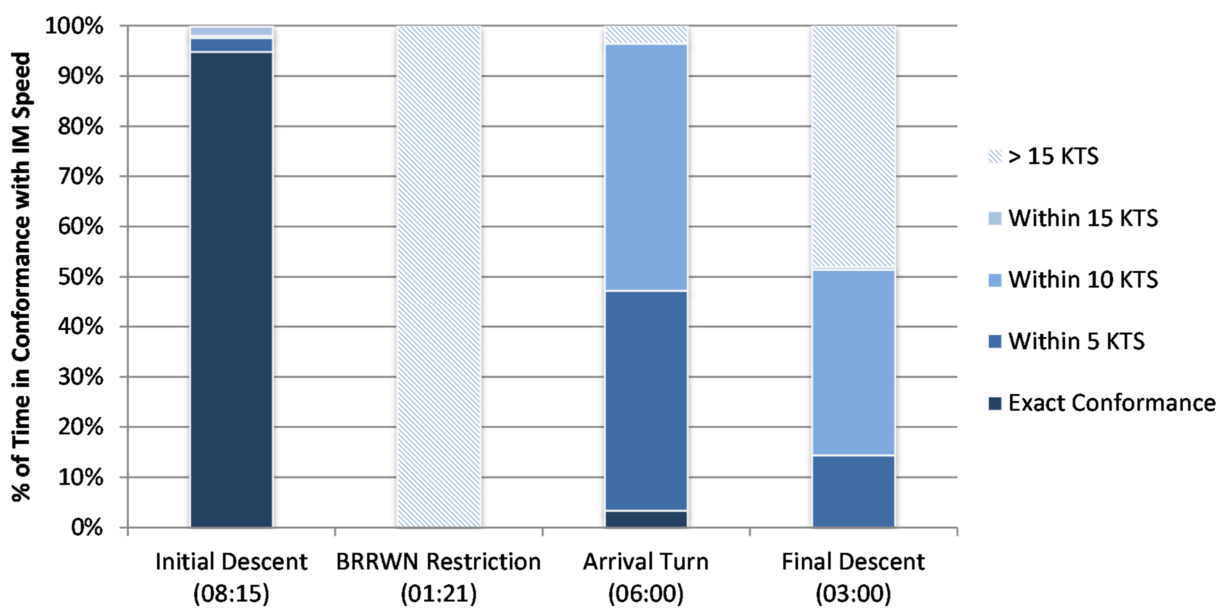


Figure 4-6. The time duration in minutes:seconds for each phase is shown below the phase name.

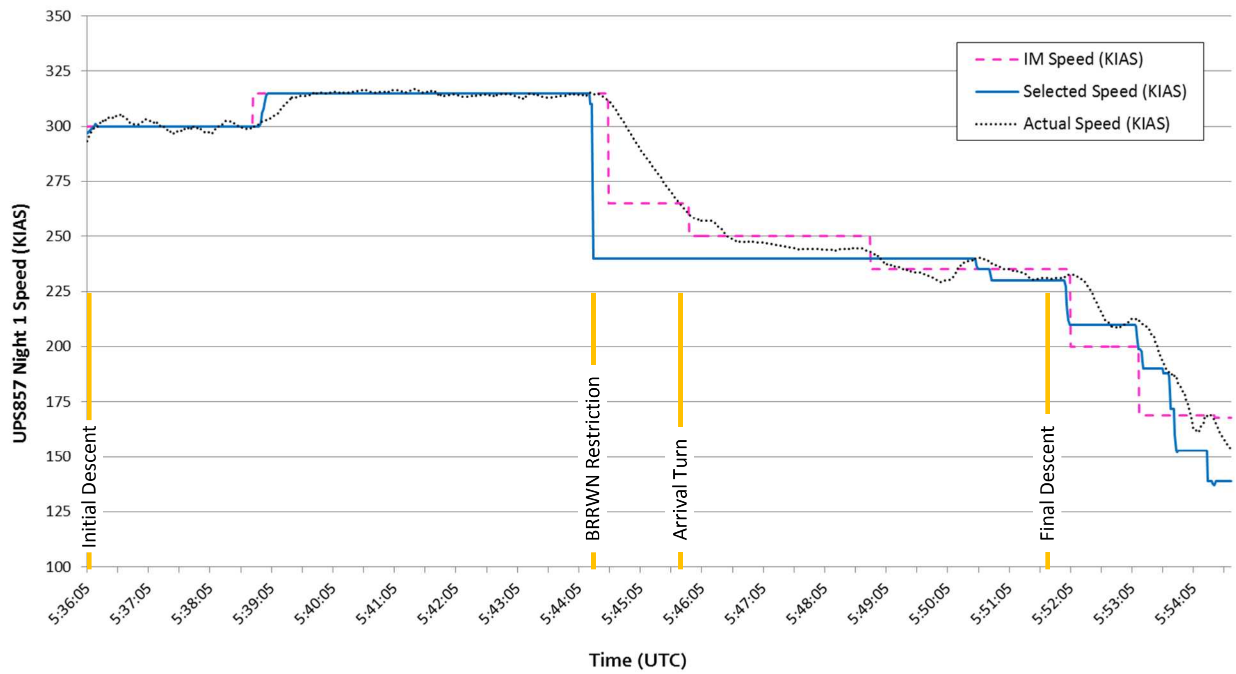


Figure 4-5. Night 1 UPS87 Speed Profile during Maintain Sub-Phases (KIAS)

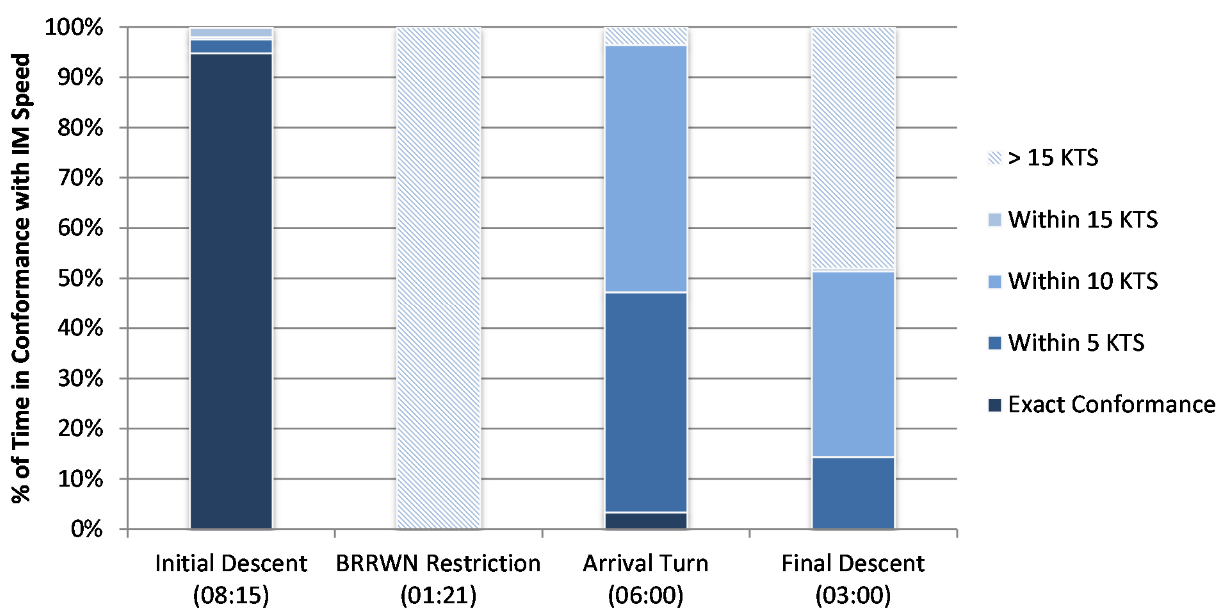


Figure 4-6. Night 1 UPS87 SEL Speed Conformance during Maintain Sub-Phases (KIAS)

During Initial Descent, the crew selected the IM Speeds and actual aircraft speed closely matched. These IM Speeds increased airspeed as spacing was slightly outside of the ASG. However, in anticipation of the Speed Crossing Restriction (SCR) at BRRWN, the crew initiated a speed change in the absence of an IM Speed change by reducing SEL to 240 kts. The IM Speed began reducing shortly thereafter (constituting an IM Speed trend change), but stepped down with values that were higher than what the pilot had selected. An examination of actual aircraft speed during this phase showed a greater than 15 kts difference between the IM Speed and actual aircraft speed more than 50% of the time. As such, conformance is considered low.

During most of the Arrival Turn Phase, the crew maintained a speed of 240 kts. Halfway between BRRWN and BRNBX, the IM Speed reduced to 235 kts and the crew reduced SEL to 230 kts, likely in anticipation of the 230 SCR at BRNBX. Although crews did not appear to intend to match IM Speeds exactly via SEL, aircraft actual speed remained within 5 to 10 kts of the IM Speed suggesting medium conformance.

Before PARCL in the Final Descent Phase, the crew did not reduce speed as aggressively as the IM Speed suggested and actual aircraft speed remained higher than the IM Speed. After UPSCO, the IM Speed reduced by 31 kts to a value that was lower than the PARCL SCR. The crew, however, responded by reducing their speed down to their FAS in steps, possibly related to the flap deployment schedule. At PARCL the IM Speed was 1 kt less than the restriction. However, the crew reduced SEL to a value 17 kts below the SCR, possibly because the actual aircraft speed began trending upward. Overall IM Speed conformance during this phase was medium, as SEL was within 10 kts of the IM Speed just over half the time.

Although the crew did not appear to place a priority on matching the IM Speeds exactly during the Maintain Phase, actual aircraft speed was within 10 kts of the IM Speed for most of the period and overall spacing after the achieve-by point remained within +/- 7 seconds of the ASG. Final spacing when the Target Aircraft touched down was 6 seconds inside of the ASG. A summary of overall conformance by phase is provided in Table 4-3. The spacing performance, IM Speeds, and crew-initiated changes for UPS857 Night 1 are provided in Figure 4-7.

Table 4-3. UPS857 Night 1 Speed Conformance Summary

Night	IM-S Flight	IM Speed Conformance	Spacing at Achieve-by Point Relative to ASG (sec)	IM Speed Conformance Spacing Mean (x) and Standard Deviation (SD) (Seconds, relative to ASG)				Average Maintain Spacing Relative to ASG (sec)	Spacing Relative to ASG at TGT TD (sec)
		Achieve		Initial Descent	BRRWN Restriction	Arrival Turn	Final Descent		
1	**UPS857**	**High**	**+4**	**High** x = 5.3 SD = 1.2	**Low** x = 6.0 SD = 0.8	Medium x = 1.3 SD = 1.4	Medium x = -1.2 SD = 2.1	**x = 3.0 SD = 3.0**	**-6**

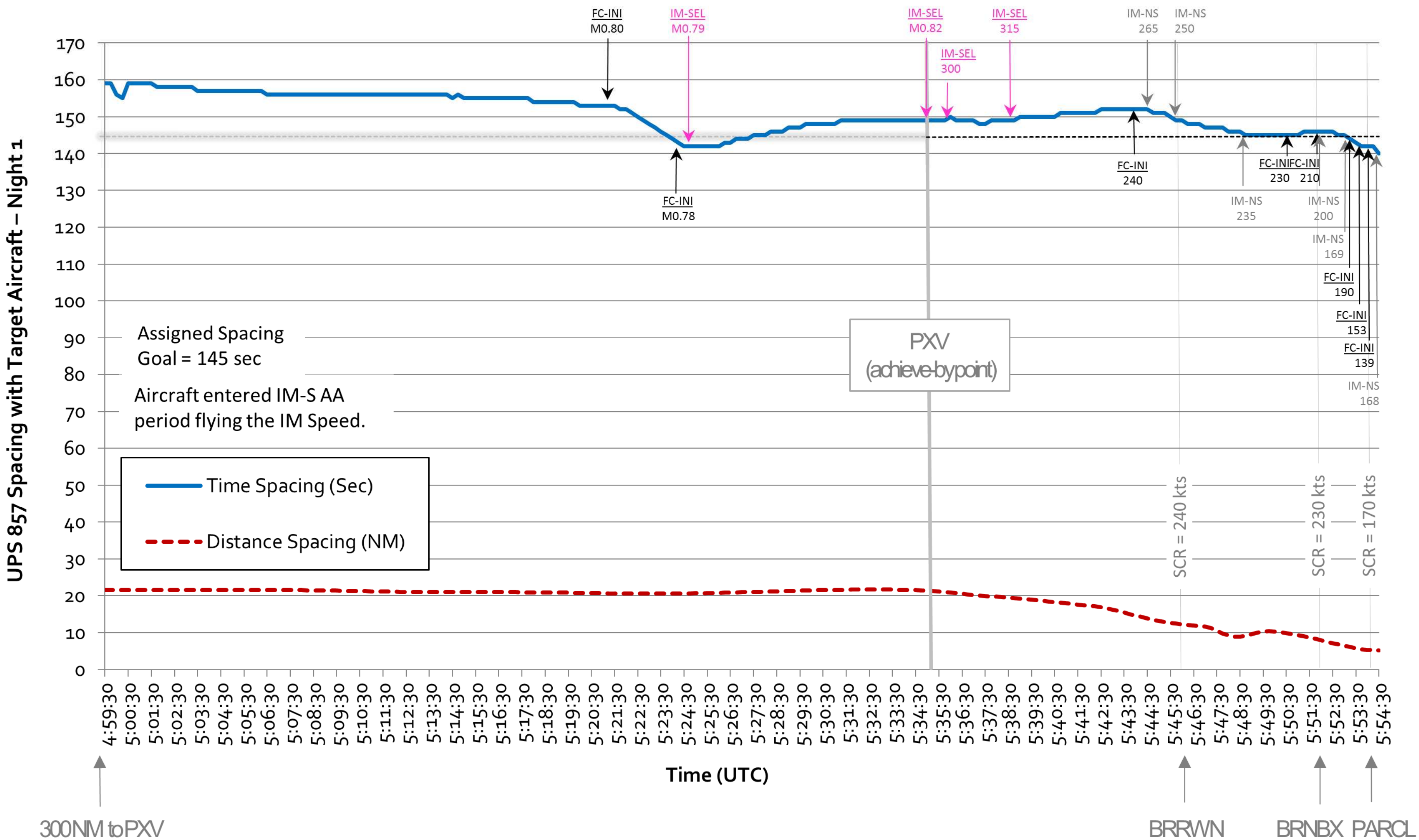


Figure 4-7. UPS857 Night 1 Spacing Performance

UPS919 → UPS905 → UPS903 → **UPS857** → UPS921

4.2.3 UPS903 Night 1 Flight Summary

Profiles of IM, Selected, and Actual Mach Speeds for UPS903 during the IM-S AA Achieve Phase are summarized in Figure 4-8. UPS903 entered the phase flying approximately M0.03 slower than the IM Speed, although the IM Speed changed to match the SEL value shortly thereafter. For much of the Achieve Phase, the crew closely conformed with the IM Speeds although they occasionally adjusted the SEL independently. Twenty minutes into the period the crew increased SEL by M0.07. This is likely due to pre-coordination goal of aircraft maintaining M0.80 when all aircraft achieved their initial positioning. The IM Speed increased a few minutes later to M0.80 and the crew adjusted SEL to match. Overall conformance during this phase is considered high.

This phase also exhibited an IM Speed trend change. Initially the IM Speeds were attempting to slow the aircraft to open up spacing with the target. Then, shortly after spacing became larger than the ASG, the IM Speed increased to close the gap.

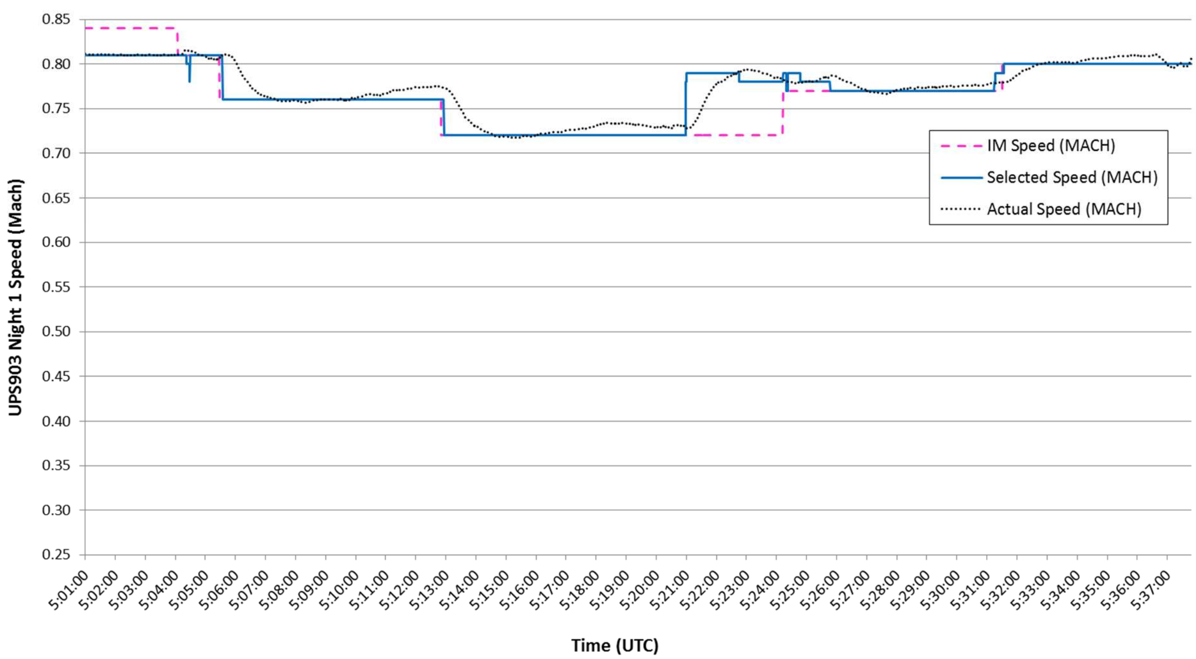


Figure 4-8. Night 1 UPS903 Speed Profile (MACH)

Profiles of IM, Selected, and Actual KIAS Speeds during the descent and arrival are shown in Figure 4-9. The percent of time SEL was in conformance with the IM Speed during this period is shown in Figure 4-10. The time duration in minutes:seconds for each phase is shown below the phase name.

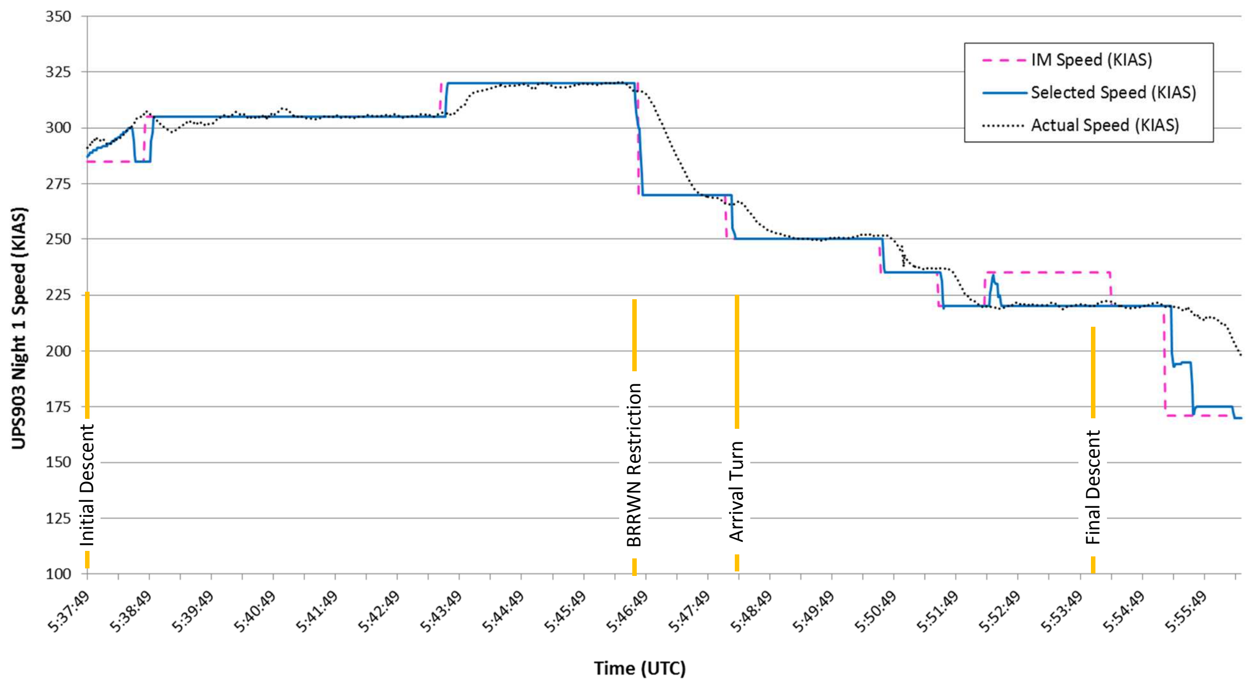


Figure 4-9. Night 1 UPS903 Speed Profile (KIAS)

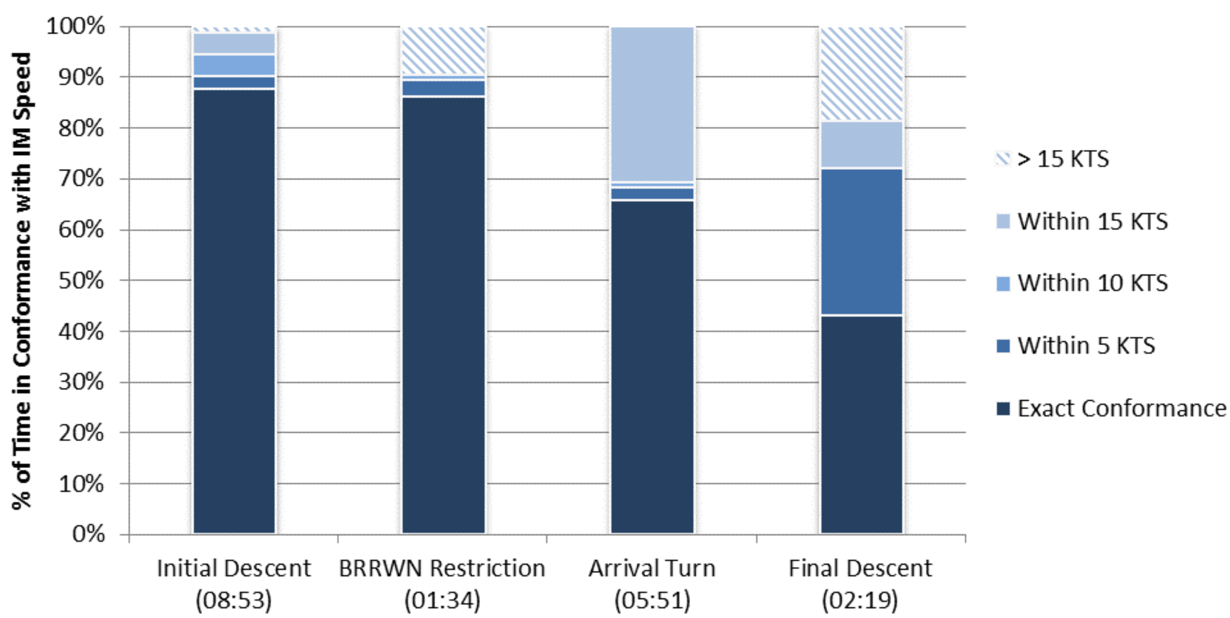


Figure 4-10. Night 1 UPS903 SEL Speed Conformance during Maintain Sub-Phases (KIAS)

During Initial Descent, the crew selected the IM Speeds and actual and SEL aircraft speeds closely conformed to the IM Speed. A second IM Speed trend change occurred shortly before BRRWN and suggested reducing SEL by 50 kts. Despite this value being 10 kts above the BRRWN SCR, the crew complied exactly. As such, conformance during the Initial Descent and BRRWN Restriction Phases is considered high.

Conformance and compliance remained high during the Arrival Turn Phase, and actual aircraft speed tracked the IM Speeds and crew inputs. However, a third IM Speed trend change occurred late in the Arrival Turn Phase and attempted to increase speed by 15 kts. The spacing data shows that aircraft spacing was starting to open and the IM Speed increase was likely an attempt to stabilize it. However, after initially complying with the higher IM Speed, the crew quickly reduced SEL back to its previous value (220 kts) as they had flaps out. Spacing then continued to increase; however, the IM Speed reduced back to the crew's SEL level, resulting in a fourth IM Speed trend change.

Just before UPSCO, in the Final Descent Phase, the crew stepped down to respond to a SEL of 175 kts for an IM Speed of 171 kts. The crew then selected a following reduction to 170 kts and the IM Speed matched the SCR at PARCL. The crew selected the IM Speed, but reduced speed just before crossing PARCL (which occurred after the IM-S AA period). From Figure 4-9, it appears that the initially achieved deceleration rate was low and actual aircraft speed lagged SEL and the IM Speed. Conformance is considered medium for this phase since SEL was within 10 kts of the IM Speed more than half the time.

Spacing at the achieve-by point was 1 second inside of the ASG, and overall spacing after that point remained within +/- 7 seconds of the ASG. Final spacing when the Target Aircraft touched down was 7 seconds inside of the ASG. With a greater aircraft deceleration rate, it is likely that the final spacing would have been even closer to the ASG. A summary of overall conformance by phase is provided in Table 4-4. The spacing performance, IM Speeds, and crew-initiated changes for UPS903 Night 1 are provided in Figure 4-11.

Table 4-4. UPS903 Night 1 Speed Conformance Summary

Night	IM-S Flight	IM Speed Conformance	Spacing at Achieve-by Point Relative to ASG (sec)	IM Speed Conformance Spacing Mean (x) and Standard Deviation (SD) (Seconds, relative to ASG)				Average Maintain Spacing Relative to ASG (sec)	Spacing Relative to ASG at TGT TD (sec)
		Achieve		Initial Descent	BRRWN Restriction	Arrival Turn	Final Descent		
1	**UPS903**	**High**	**-1**	**High** x = 1.3 SD = 2.1	**High** x = 2.3 SD = 0.5	Medium x = -0.5 SD = 2.1	Medium x = 2.7 SD = 3.7	**x = 1.0** **SD = 2.5**	**-7**

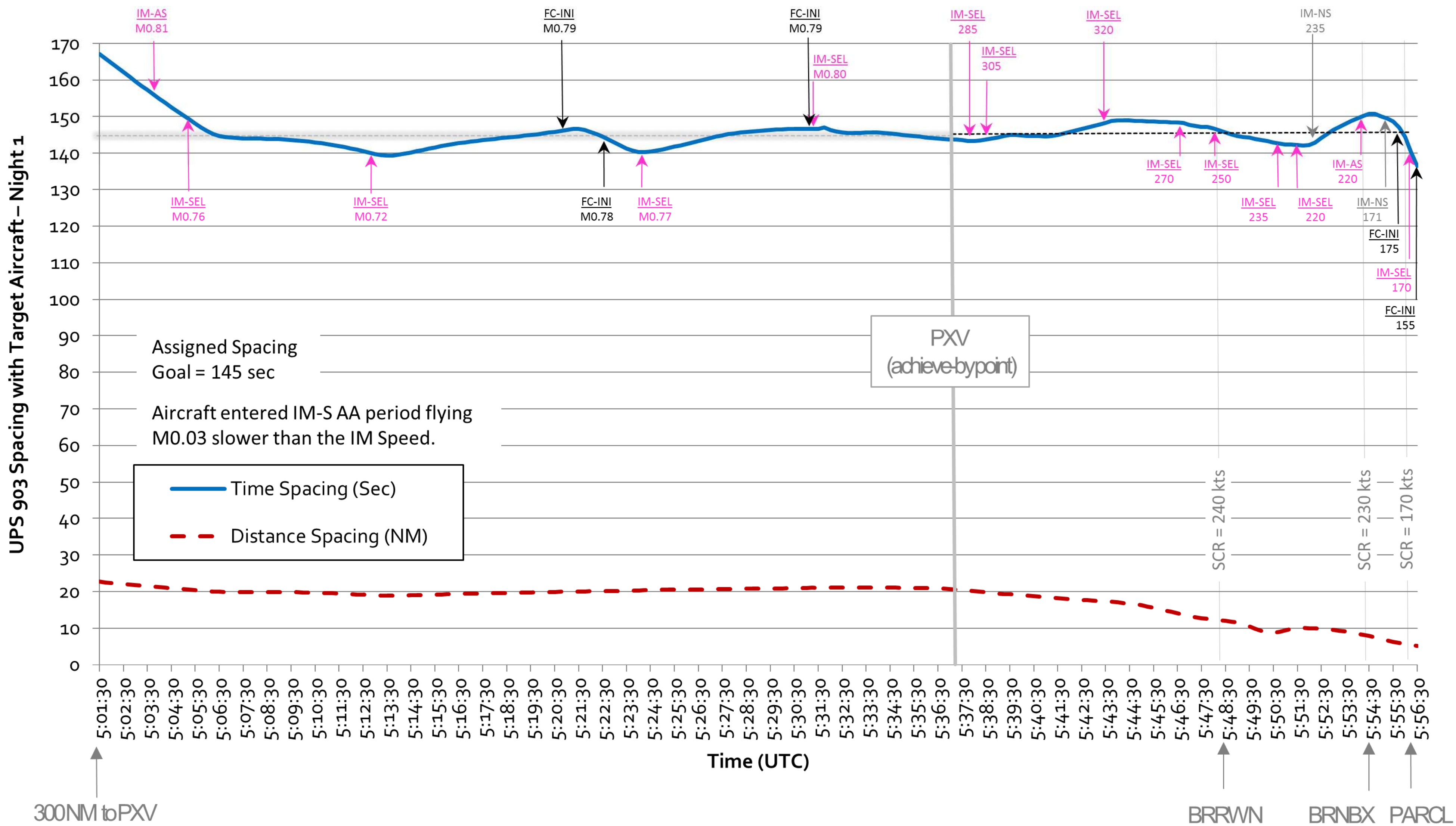


Figure 4-11. UPS903 Night 1 Spacing Performance

UPS919 → UPS905 → **UPS903** → UPS857 → UPS921

4.2.4 UPS919 Night 1 Flight Summary

Profiles of IM, Selected, and Actual Mach Speeds for UPS919 during the IM-S AA Achieve Phase are summarized in Figure 4-12. Night 1 UPS919 Speed Profile (MACH) UPS919 entered the IM-S AA period with the crew flying M0.01 slower than the IM Speed of M0.84. For most of the Achieve period, SEL and actual aircraft speed were in conformance with the IM Speed and spacing happened to be within 10 seconds of the ASG. The crew received two IM Speeds that they selected, but as they approached the achieve-by point, also initiated a speed reduction for unclear reasons. Ultimately they closed to 1 second outside of the ASG at the achieve-by point.

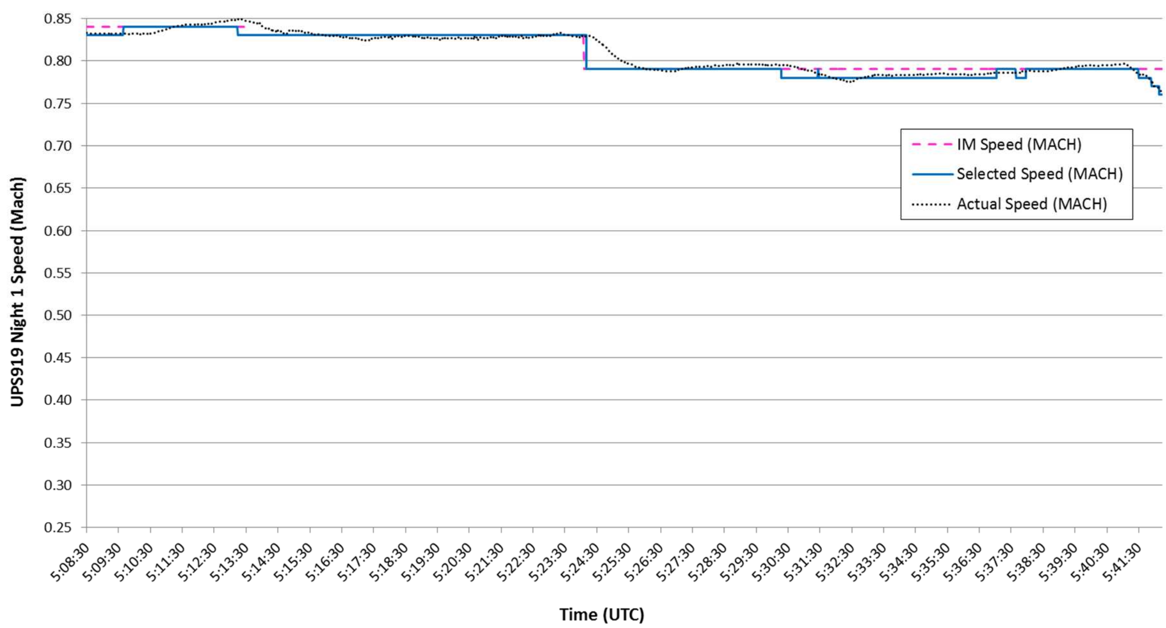


Figure 4-12. Night 1 UPS919 Speed Profile (MACH)

Profiles of IM, Selected, and Actual KIAS Speeds during the descent and arrival are shown in Figure 4-13. The percent of time SEL was in conformance with the IM Speed during this period is shown in Figure 4-14. The time duration in minutes:seconds for each phase is shown below the phase name.

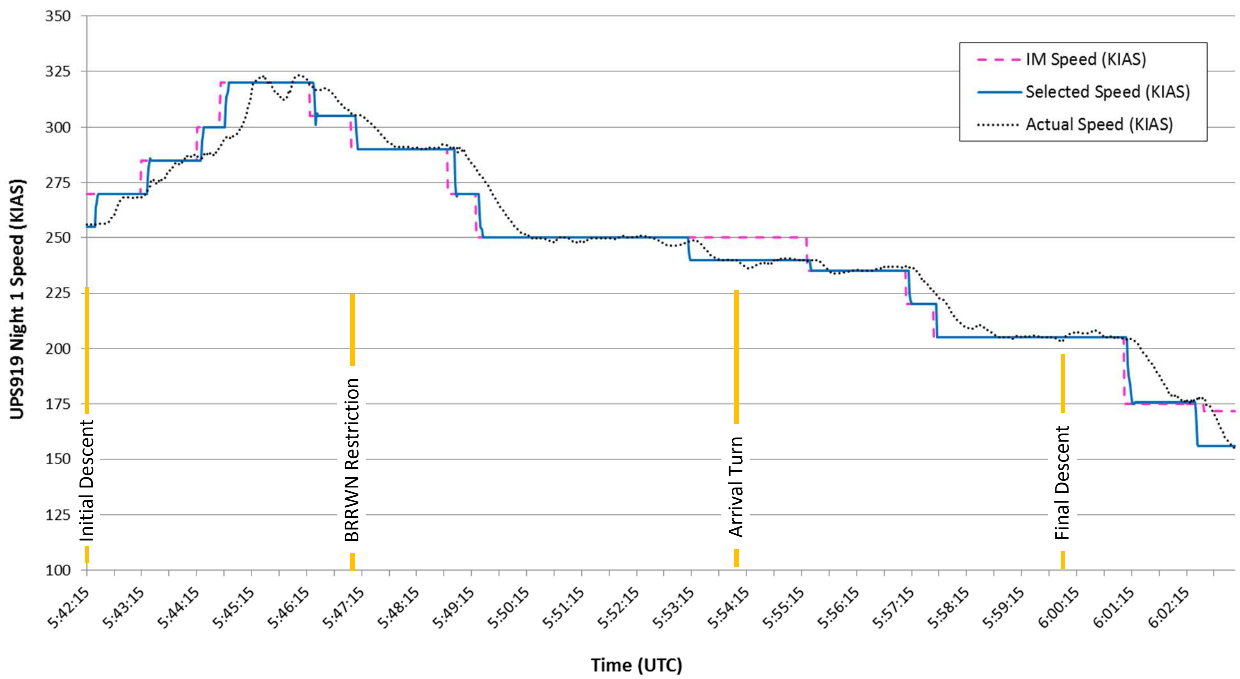


Figure 4-13. Night 1 UPS919 Speed Profile (KIAS)

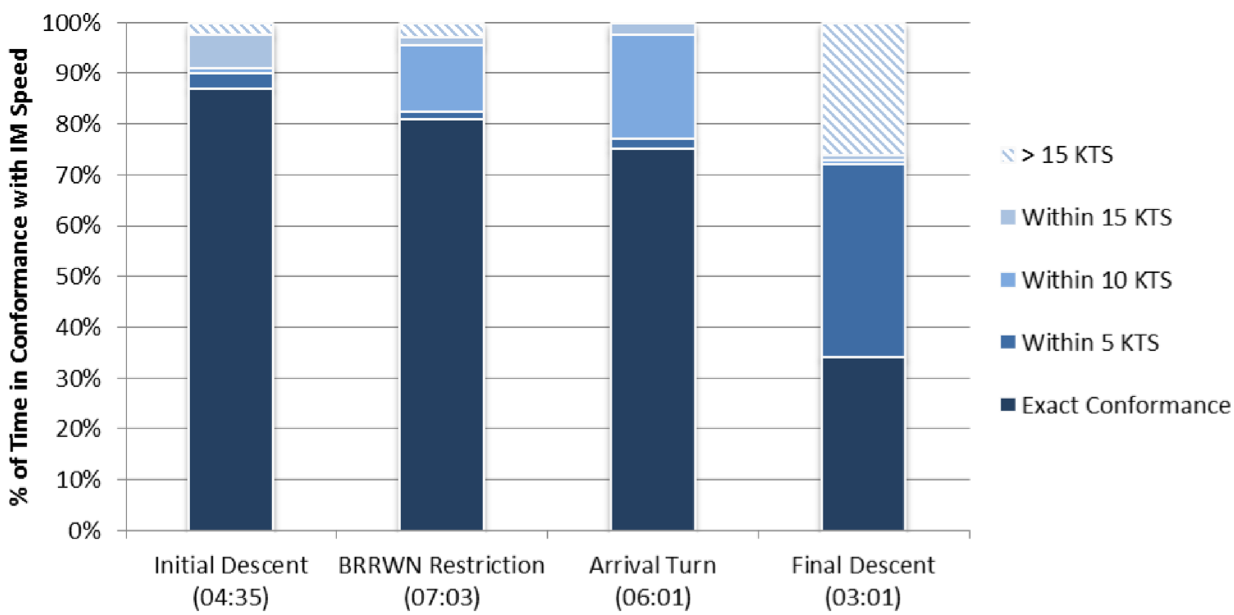


Figure 4-14. Night 1 UPS919 SEL Speed Conformance during Maintain Sub-Phases (KIAS)

During the Initial Descent Phase, aircraft spacing with the target began to increase and the crew received several IM Speeds in short succession that attempted to increase aircraft speed in order to close the gap. Crews complied exactly with each of the IM Speeds and actual aircraft speed tracked the SEL inputs. As the spacing started to decrease, IM Speeds began decreasing, resulting in an IM Speed trend change. These were likely a result of the Target Aircraft slowing down to meet the BRRWN SCR. The crew selected the IM Speeds throughout the Initial Descent period and conformance is rated as high.

The crew continued to comply with the IM Speeds exactly through the BRRWN Restriction Phase. However, shortly before the BRRWN fix, the IM Speed was 250 kts and the crew slowed to 240 kts, noting to the observer that this was the FMC limit. Shortly after, the IM Speed reduced to 235 kts and the crew quickly complied. SEL conformance was within 5 kts of the IM Speed for more than 80% of this phase, resulting in a categorization of high.

Conformance in the Arrival Turn Phase was within 5 kts for approximately 75% of the period, and 10 kts approximately 78% of the period. Normally this would result in the medium conformance categorization. However, the reason for the non-conformance was the IM Speed maintaining 250 kts over BRRWN. As soon as the IM Speed reduced, the crew quickly complied. As such, it was clear that the crew was attempting to conform to the IM Speed to the degree possible and so the conformance rating for this phase will continue to be considered high.

During the Final Descent Phase, the crew selected the IM Speed which was below the UPSCO SCR. However, the crew increased speed by 1 kt, for unclear reasons, before crossing the fix. The crew then input a SEL of 156 kts, independent of the IM Speed which was still reading 175 kts. The spacing was only 3 seconds greater than the ASG, but trending toward it. The IM Speed changed shortly thereafter to 172 kts, resulting in a speed increase relative to SEL. The crew input their FAS and did not select this IM Speed. Conformance during this phase was medium, apparently because the IM Speed did not reduce at the end as quickly as the crew felt appropriate.

Final spacing was 147 seconds (2 seconds outside the ASG) when the Target Aircraft touched down. Overall spacing during the Maintain Phase remained within +/- 8 seconds of the ASG and within +/- 5 seconds for the majority of the period. A summary of overall conformance by phase is provided in Table 4-4. The spacing performance, IM Speeds, and crew-initiated changes for UPS919 Night 1 are provided in Figure 4-15.

Table 4-5. UPS919 Night 1 Speed Conformance Summary

Night	IM-S Flight	IM Speed Conformance	Spacing at Achieve-by Point Relative to ASG (sec)	IM Speed Conformance Spacing Mean (x) and Standard Deviation (SD) (Seconds, relative to ASG)				Average Maintain Spacing Relative to ASG (sec)	Spacing Relative to ASG at TGT TD (sec)
		Achieve		Initial Descent	BRRWN Restriction	Arrival Turn	Final Descent		
1	**UPS919**	**High**	**+1**	**High** x = 5.8 SD = 2.2	**High** x = 0.9 SD = 2.4	**High** x = 1.4 SD = 1.0	Medium x = 3.7 SD = 0.9	**x = 2.5 SD = 2.7**	**+2**

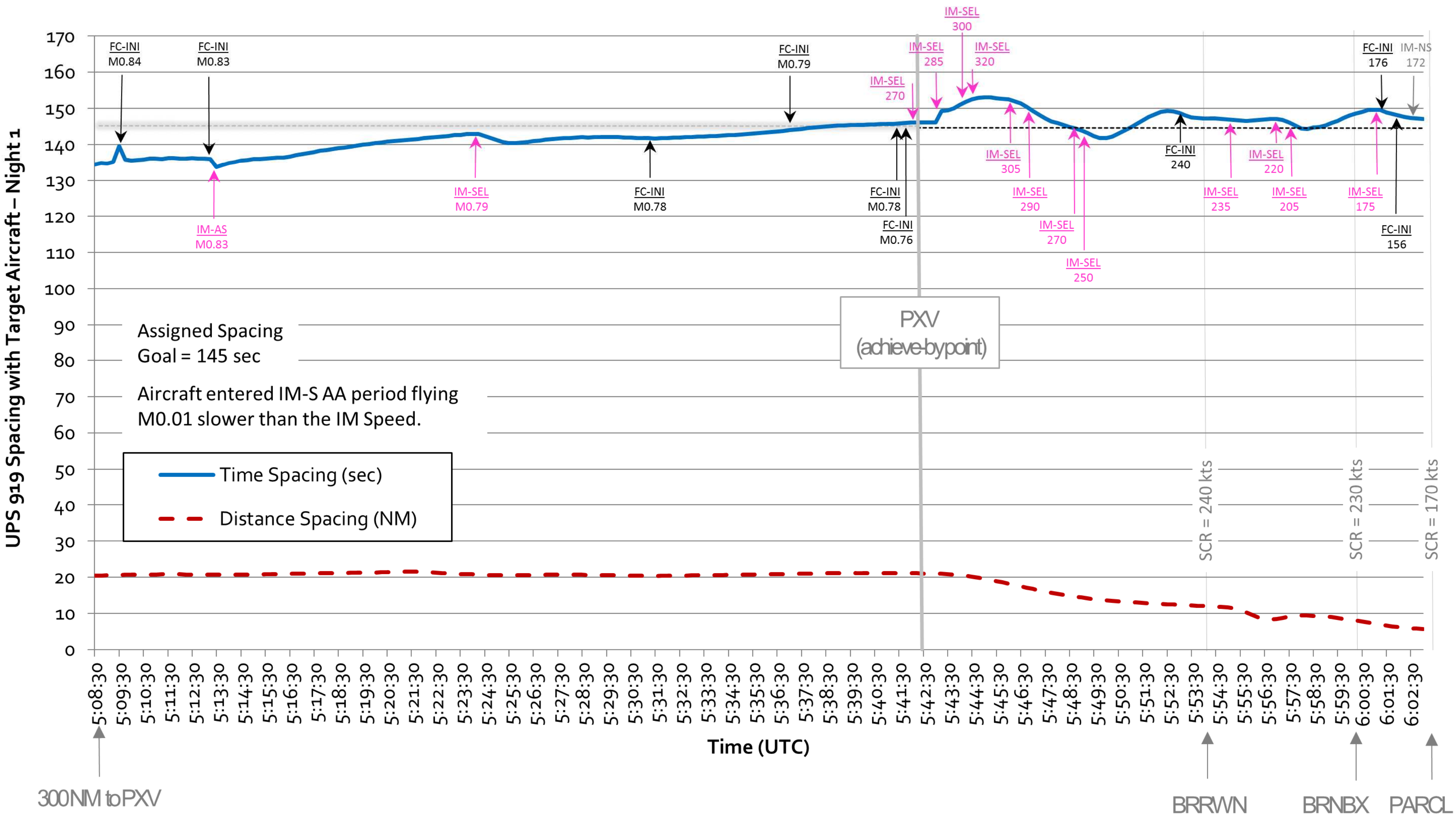


Figure 4-15. UPS919 Night 1 Spacing Performance

UPS919 → UPS905 → UPS903 → UPS857 → UPS921

4.2.5 Night 2 Sequence

Departure times were calculated and instituted by UPS to provide the best chance of successful airborne IM-S AA pairings. The aircraft departure sequence is shown in Table 4-6.

Table 4-6. Night 2 Aircraft Departure Sequence

Flight ID	Departure Gateway and Wheels Up Time (UTC)
UPS903	LAX at 0240
UPS905	LGB at 0245
UPS919	ONT at 0245
UPS857	PHX at 0301

Initial setup was performed as described previously. Figure 4-16 shows the final aircraft sequence. As noted in Table 2-7, on-board SafeRoute data collection was not available for UPS857 so its spacing performance (calculated on-board) throughout the arrival is unknown. The narrative and other results for that flight are based on observer data from the flight.

UPS919 → UPS903 → UPS905 → UPS857 → UPS921

Figure 4-16. Night 2 Final Aircraft Sequence

All IM-S AA aircraft arrived and landed on 35R at SDF via BRWWN CDA without ATC intervention. A graphic representation of the flight progression is provided in Appendix C.

4.2.6 UPS857 Night 2 Flight Summary

SafeRoute data was unavailable for this flight on Night 2, so crew actions and IM Speed behavior is derived from observer notes. Based on observer notes of aircraft speed, profiles of IM, Selected, and Actual KIAS Speeds across the Achieve and Maintain Phases are summarized in Figure 4-17.

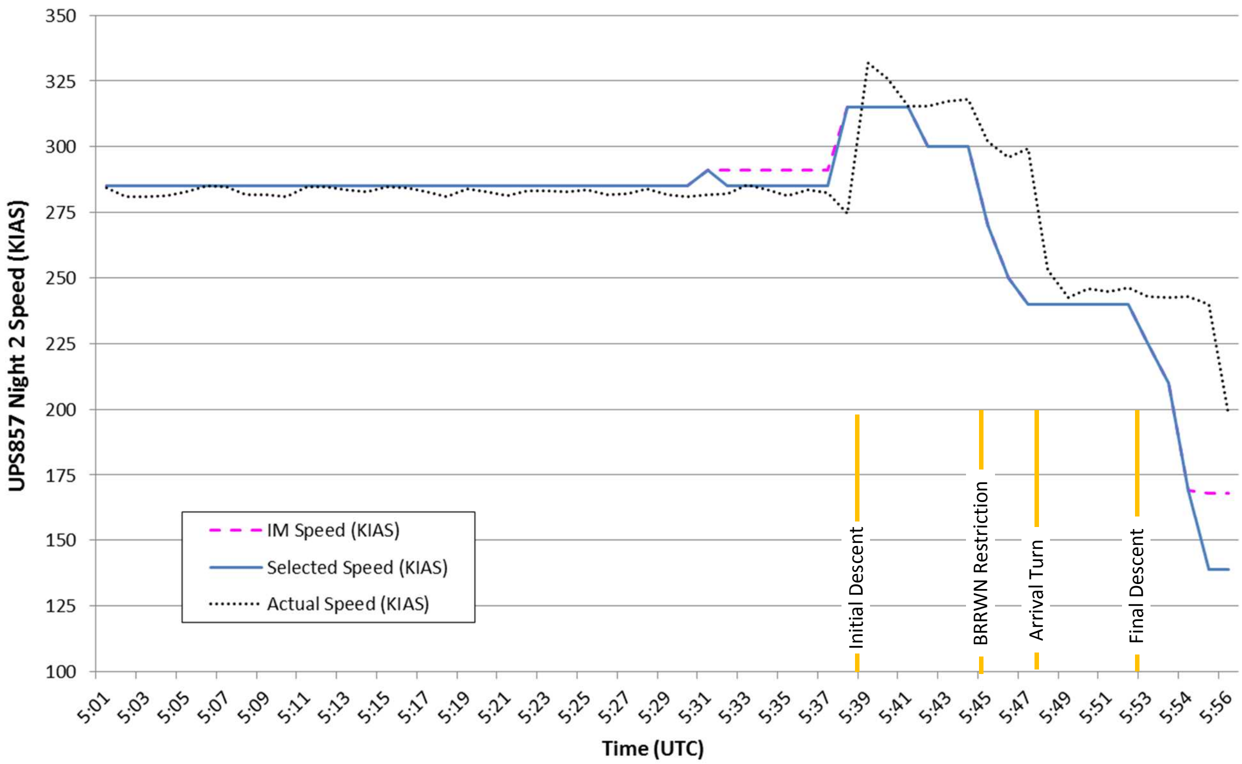


Figure 4-17. Night 2 UPS857 Speed Profile (KIAS)

At the beginning of the IM-S AA period, the crew appeared to be in compliance with the IM Speed value. The observer reports that the crew also complied closely with the IM Speeds throughout the descent, including through the speed restriction at BRRWN (though it is unknown how long crews took to respond to each new IM Speed). At BRNBX and UPSCO, the crews were reported to have selected the IM Speeds, which were below the SCR at each fix. In the Final Descent Phase, the crew did not select 1 of the 3 IM Speeds, which appeared to be related to the crew slowing to FAS without a corresponding reduction in the IM Speed. No IM Speed trend changes were observed to have occurred. Spacing performance results are not available for this flight due to the lack of detailed SafeRoute data.

4.2.7 UPS905 Night 2 Flight Summary

Profiles of IM, Selected, and Actual Mach Speeds for UPS905 during the IM-S AA Achieve Phase are summarized in Figure 4-18. UPS905 entered the IM-S AA period approximately 25 seconds outside of the ASG and flying M0.02 faster than the IM Speed received outside the IM-S AA period. After approximately 23 minutes, the crew decreased speed to M0.82 in response to a speed-up IM Speed change to M0.84. However, nearly four minutes later the crew selected M0.84 and established conformance with the IM Speed. The crew then initiated several additional independent speed changes throughout this phase. The observer noted that the crew was manually attempting to manage a 22 NM distance with the Target Aircraft, which indicates that the crew did not prioritize conformance with the IM Speed during this period. UPS905 spacing was 8 seconds higher than the ASG at the achieve-by point. Conformance during the Achieve Phase was medium as the crew kept SEL within M0.02 of the IM Speed approximately 60% of the time.

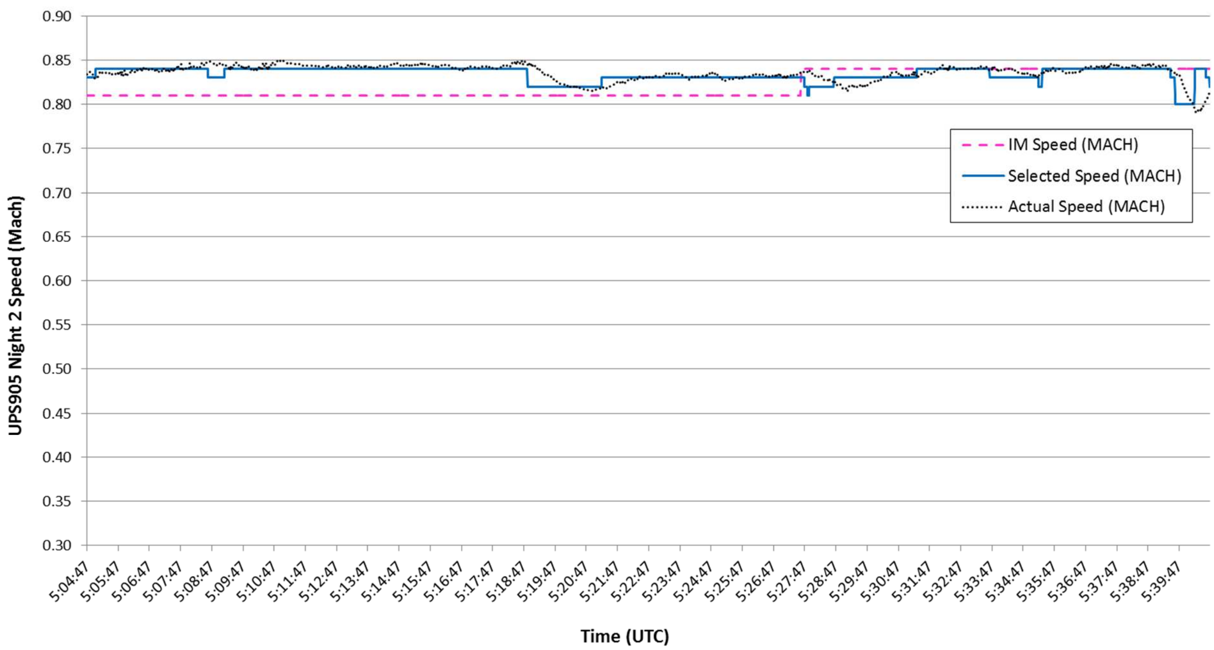


Figure 4-18. Night 2 UPS905 Speed Profile (MACH)

Profiles of IM, Selected, and Actual KIAS Speeds during the descent and arrival are shown in Figure 4-19. The percent of time SEL was in conformance with the IM Speed during this period is shown in Figure 4-20. The time duration in minutes:seconds for each phase is shown below the phase name.

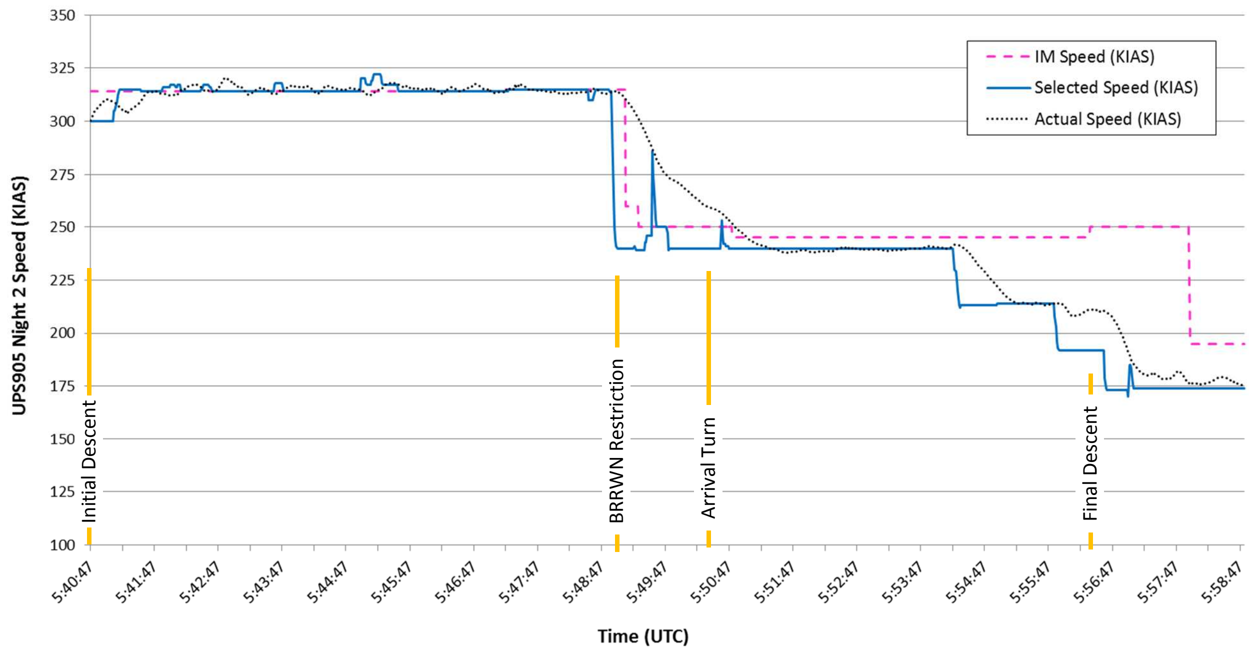


Figure 4-19. Night 2 UPS905 Speed Profile (KIAS)

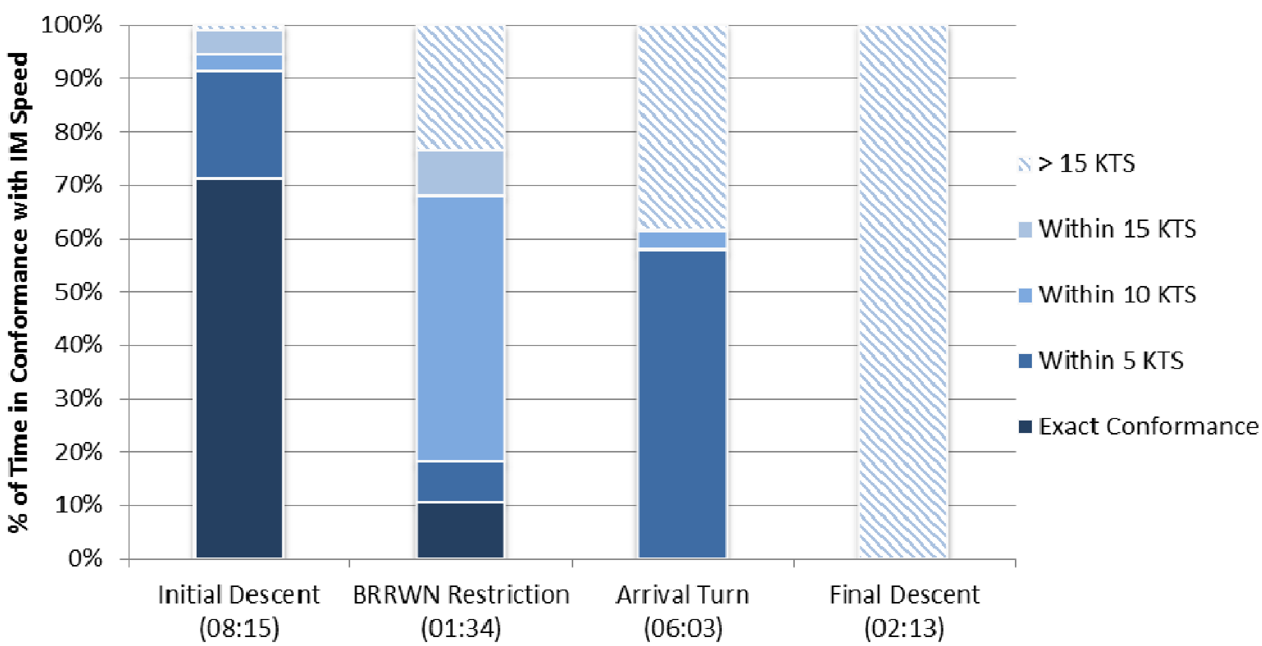


Figure 4-20. Night 2 UPS905 SEL Speed Conformance during Maintain Sub-Phases (KIAS)

Conformance with the IM Speed was high during the Initial Descent Phase, though the crew initiated several minor speed changes within +/- 6 kts. After these adjustments, they nearly always returned to the IM Speed value. Spacing during this phase tended to be within 10 seconds of the ASG.

Possibly in anticipation of the speed restriction at BRRWN, the pilot led the IM Speed by reducing SEL to 240 kts. The IM Speed began reducing shortly thereafter to 250 kts, but stepped down. The reduction to BRRWN constituted the first IM Speed trend change. Since spacing remained outside of the ASG, the IM Speed remained at 245-250 kts for most of the BRRWN Restriction and Arrival Turn Phases. The crew maintained 240 kts for most of this period, likely due to the 240 kt SCR at BRRWN. However, the crew momentarily increased SEL to 286 kts and 250 kts during the period. It is not exactly clear why, although the observed noted around this time that the “crew seem to by flying relative to picnic table.” Conformance during this phase was medium as SEL was within 10 kts of the IM Speed for almost 70% of the period.

A sharp rise in spacing occurred in the Arrival Turn Phase after JMCSY. Despite the IM Speed maintaining 245 kts to attempt to close the gap with the Target Aircraft, the crew appeared to be particularly aggressive in meeting the later crossing restrictions. The aircraft crossed BRNBX and UPSCO 19 and 14 kts slower than the SCRs. This crew also appeared to step down to FAS earlier than other flights. During the initial crew speed reduction, the observer noted that “the crew feels CDA is too steep and thus they are carrying too much speed.” It is unclear, however, how the crew came to this determination as they crossed BRNBX 20 kts slower than its SCR. These early slowdowns were not in response to the IM Speeds and contributed to the loss in spacing.

An IM Speed trend change was observed just before BRNBX, as the IM Speed increased from 245 to 250 kts. This speed-up was likely in response to the developing spacing gap. However, the trend reversed again in the Final Descent Phase as the IM Speeds began stepping down toward the FAS. Conformance during this phase was medium as SEL was within 10 kts of the IM Speed for approximately 60% of the period.

The flight also did not select the single IM Speed during the Final Descent Phase. At this point, the low conformance appeared to be related to the crew stepping down to their FAS ahead of corresponding IM Speed reductions. The IM Speeds likely remained high to try to close the developing spacing gap.

Overall Conformance with the IM Speed was low after BRRWN and the crew made many SEL changes independent of the IM Speed. Spacing during the Maintain Phase remained within +/- 10 seconds of the ASG, until spacing increased at the end of the Arrival Turn Phase and into Final Descent. IM Speed conformance decreased and the final spacing was 46 seconds outside of the ASG and higher than all but one of the other flights. A summary of overall conformance by phase is provided in Table 4-7.

Table 4-7. UPS905 Night 2 Speed Conformance Summary

Night	IM-S Flight	IM Speed Conformance	Spacing at Achieve-by Point Relative to ASG (sec)	IM Speed Conformance Spacing Mean (x) and Standard Deviation (SD) (Seconds, relative to ASG)				Average Maintain Spacing Relative to ASG (sec)	Spacing Relative to ASG at TGT TD (sec)
		Achieve		Initial Descent	BRRWN Restriction	Arrival Turn	Final Descent		
2	**UPS905**	**Medium**	**+1**	**High** x = 7.9 SD = 1.1	Medium x = 4.6 SD = 0.2	Medium x = 5.3 SD = 3.6	**Low** x = 30.5 SD = 9.0	**x = 9.5** **SD = 8.8**	**+46**

The spacing performance, IM Speeds, and crew-initiated changes for UPS905 Night 2 are provided in Figure 4-21. Some runs of crew-initiated speed changes are too frequent to depict individually. These are shown with arrows depicting the boundaries of the time period and a "↔" symbol between values that show the relative change of the inputs over the previous SEL speed.

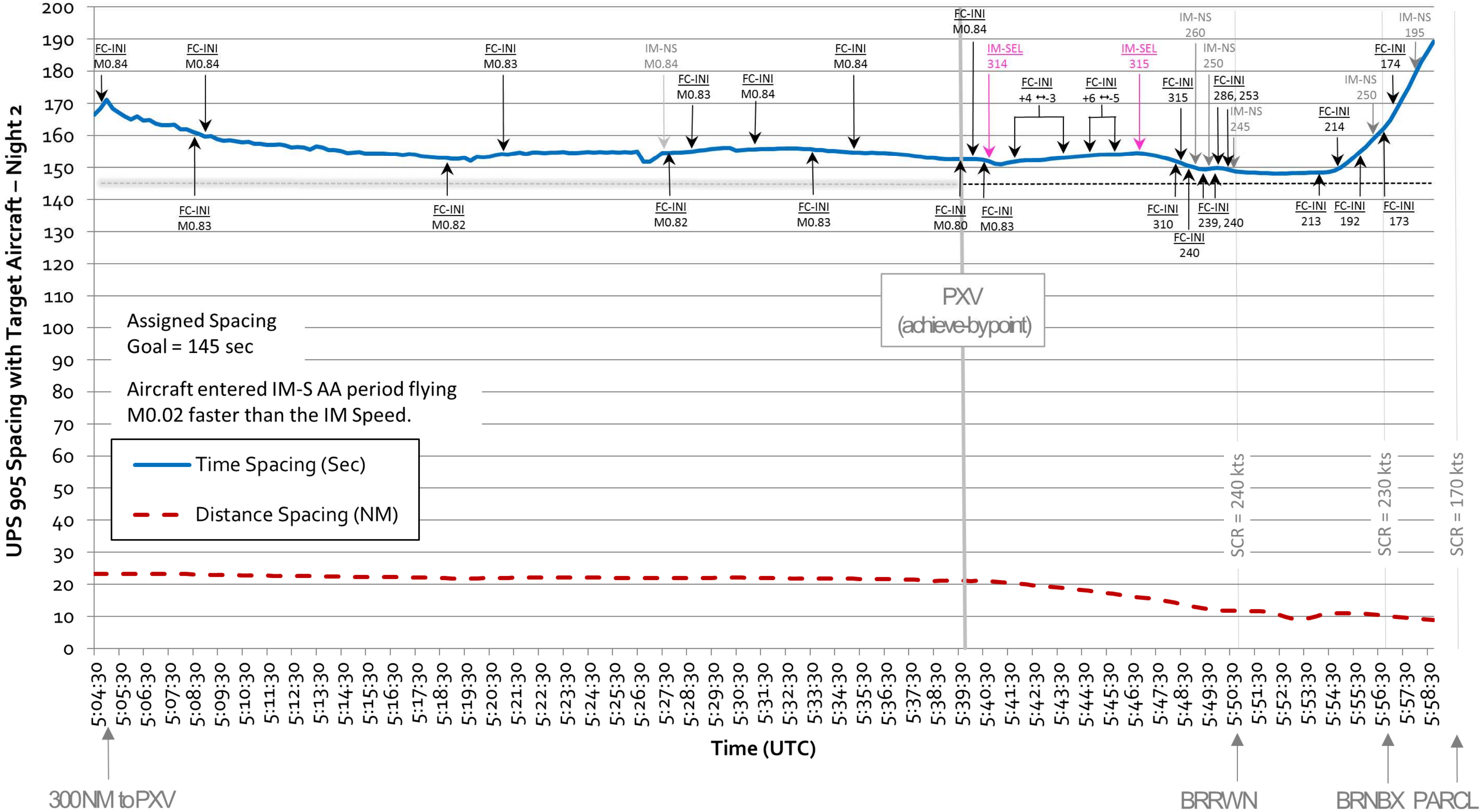


Figure 4-21. UPS905 Night 2 Spacing Performance

UPS919 → UPS903 → **UPS905** → UPS857 → UPS921

4.2.8 UPS903 Night 2 Flight Summary

On Night 2, the crew of UPS 903 switched to flying KIAS shortly inside of the Achieve Phase and well before the TOD. Therefore, profiles of IM, Selected, and Actual Speeds for UPS905 during the IM-S AA Achieve Phase are in both Figure 4-22 and Figure 4-23.

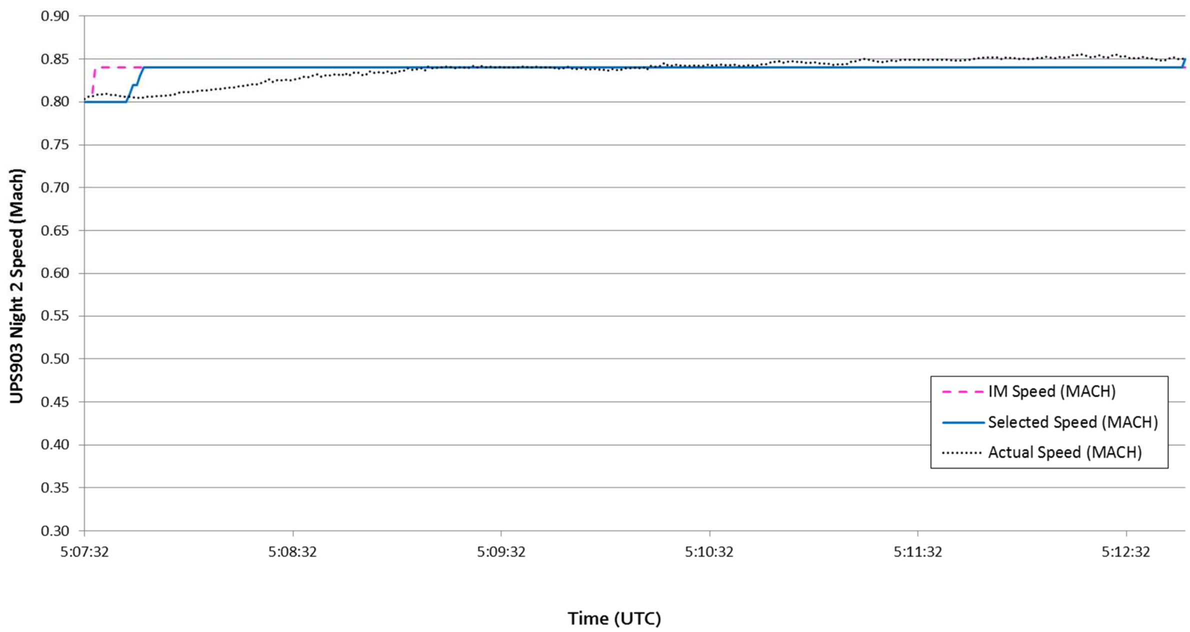


Figure 4-22. Night 2 UPS903 Speed Profile (Mach)

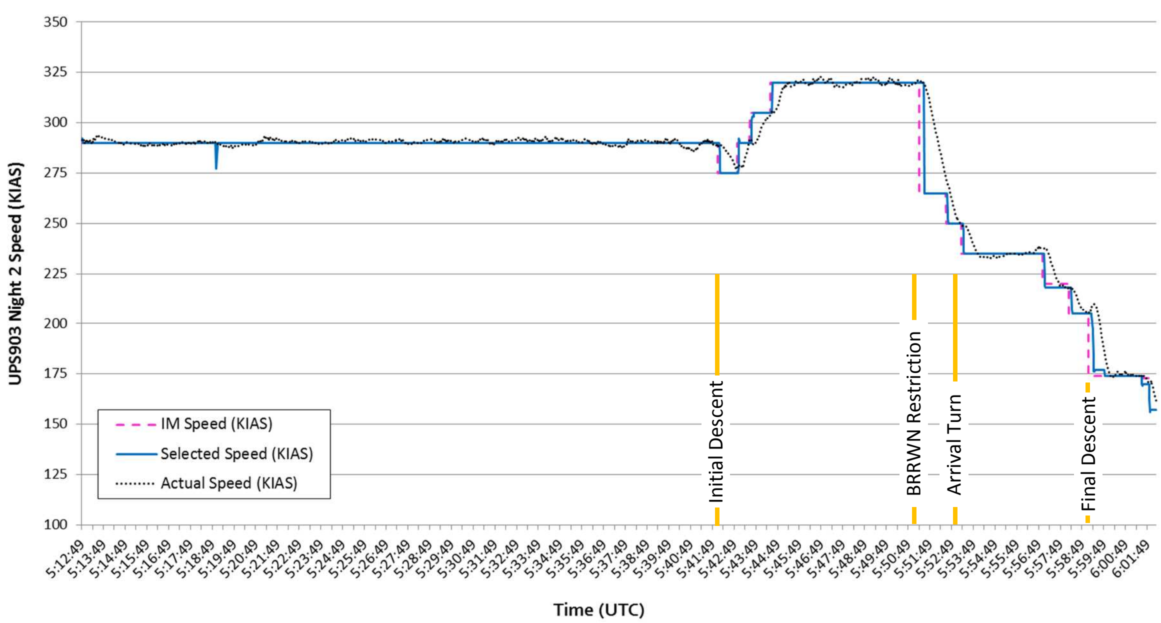


Figure 4-23. Night 2 UPS903 Speed Profile (KIAS)

UPS903 entered the IM-S AA period flying the IM Speed received outside the IM-S AA period. Spacing happened to be approximately 20 seconds outside of the ASG and opening. The crew received two IM Speeds during the Achieve period, which they quickly selected. They selected an IM Speed of 290 kts, which translated into an actual Mach speed of M0.85. The flight crossed the achieve-by point 5 seconds inside the ASG. The percent of time SEL was in conformance with the IM Speed is shown in Figure 4-24. The time duration in minutes:seconds for each phase is shown below the phase name.

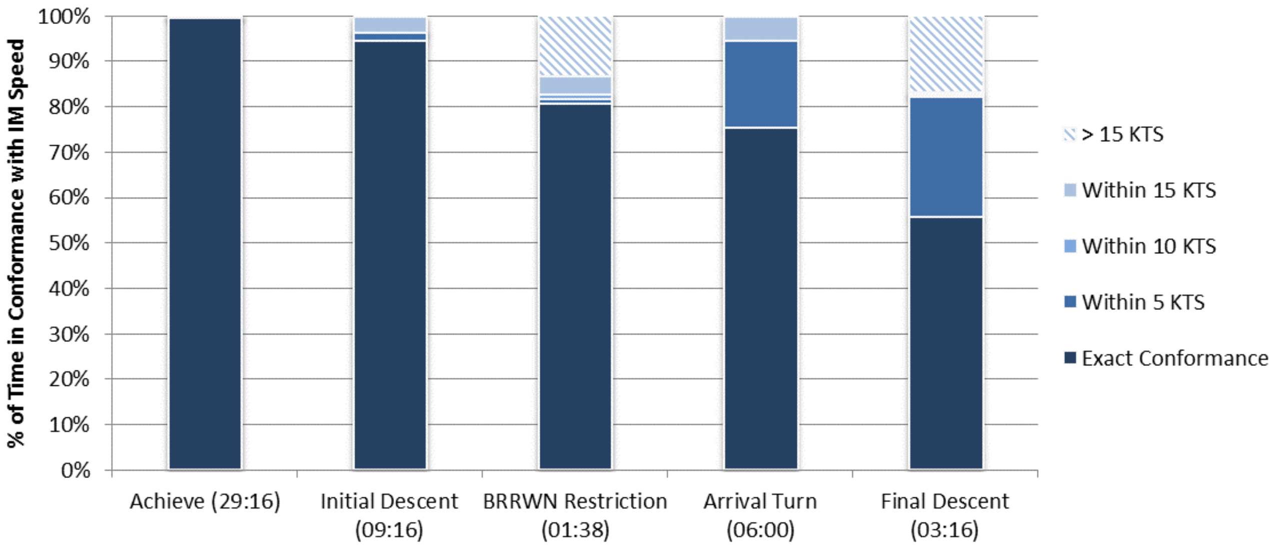


Figure 4-24. Night 2 UPS903 SEL Speed Conformance (KIAS)

At the start of Initial Descent, an IM Speed was presented that attempted to decrease SEL to increase the spacing. The crew selected the IM Speed and approximately 1 minute later received a series of IM Speeds that suggested increasing speed. These constituted an IM Speed trend change and coincided with an increase in spacing to outside of the ASG. The crew quickly selected these IM Speeds. A second IM Speed trend change was observed before the speed restriction at BRRWN. Whereas the previous IM Speeds were intended to increase aircraft speed to close or maintain spacing, the series before BRRWN attempted to reduce SEL due to the lead aircraft slowing down. The crew quickly stepped down SEL to comply with both IM Speeds during this period and crossed BRRWN with IM Speed and SEL values 10 kts higher than the SCR, and actual aircraft speed 15 kts higher.

After BRRWN, the crew selected the next slow-down IM Speed. After the turn at JMCSY, spacing exactly matched the ASG and the next two IM Speeds continued to step down the speed. The crew selected a speed of 218 kts in response to an IM Speed of 220 kts; it is unclear why they did not conform exactly to the IM Speed. Nearly 1 minute later, the IM Speed decreased again to 205 kts and the crew complied. The flight then crossed BRNBX 24 kts slower than the SCR and 3 seconds inside of the ASG.

Just after BRNBX, the crew selected an IM Speed reduction to 174 kts and maintained this Speed across UPSCO. Spacing remained just inside the ASG and it appeared the IM Speeds were slowing earlier than other flights to try to increase spacing. Before PARCL, the IM Speed reduced to a value 3 kts greater than the SCR. In response, the crew selected the SCR value exactly. There were no IM Speed changes after PARCL and the crew began stepping the speed down to the FAS.

Spacing conformance for all of the Maintain sub-phases was high, and overall spacing performance was within +/- 5 seconds of the ASG. The flight had a final spacing 8 seconds inside the ASG when the Target Aircraft touched down. A summary of overall conformance by phase is provided in Table 4-8. The spacing performance, IM Speeds, and crew-initiated changes for UPS903 Night 2 are provided in Figure 4-25.

Table 4-8. UPS903 Night 2 Speed Conformance Summary

Night	IM-S Flight	IM Speed Conformance	Spacing at Achieve-by Point Relative to ASG (sec)	IM Speed Conformance Spacing Mean (x) and Standard Deviation (SD) (Seconds, relative to ASG)				Average Maintain Spacing Relative to ASG (sec)	Spacing Relative to ASG at TGT TD (sec)
		Achieve		Initial Descent	BRRWN Restriction	Arrival Turn	Final Descent		
2	**UPS903**	**High**	**-5**	**High** x = 0.7 SD = 2.4	**High** x = -1.9 SD = 1.0	**High** x = -1.9 SD = 1.0	**High** x = -4.7 SD = 1.0	**x = -1.2** **SD = 2.7**	**-8**

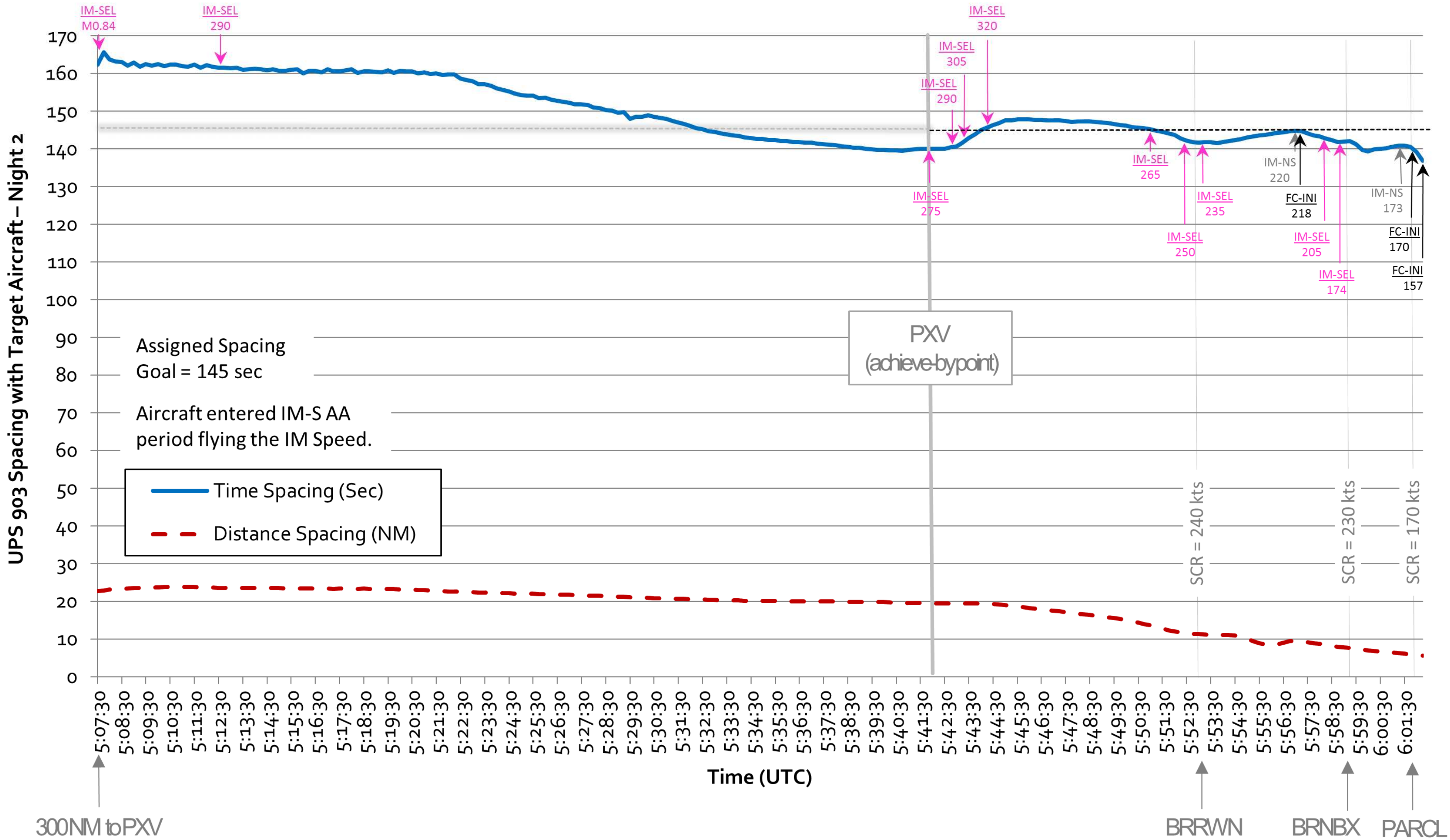


Figure 4-25. UPS903 Night 2 Spacing Performance

UPS919 → **UPS903** → UPS905 → UPS857 → UPS921

4.2.9 UPS919 Night 2 Flight Summary

Profiles of IM, Selected, and Actual Mach Speeds for UPS919 during the IM-S AA Achieve Phase are summarized in Figure 4-26. UPS919 entered the period flying M0.04 faster than the IM Speed. The observer noted that this was because ownship had a 40 kt overtake on the target; however, it is unclear why this would lead the crew to increase speed.

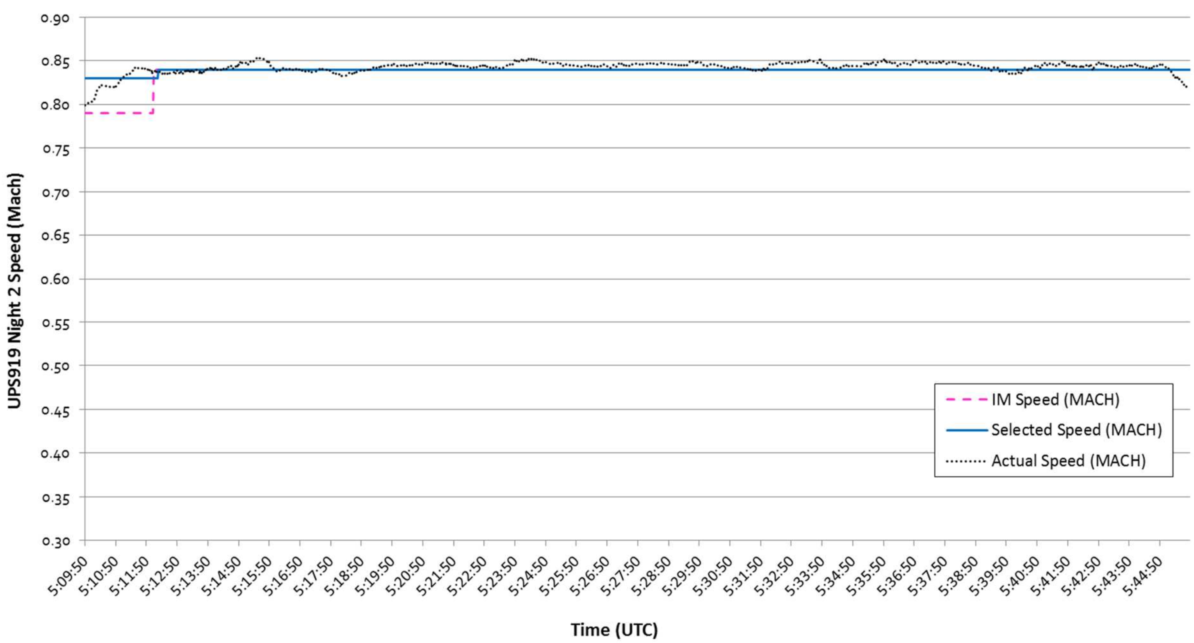


Figure 4-26. Night 2 UPS919 Speed Profile (MACH)

UPS919 entered the Achieve Phase of the IM-S AA period with 4 seconds of spacing with the Target Aircraft outside of the ASG. After approximately 4 minutes, an IM Speed of 0.84 was presented. The crew complied, but noted to the observer that they did not like the large jump in magnitude (M0.79 to M0.84). Despite high crew conformance in the Achieve Phase, UPS919 crossed the achieve-by point 22 seconds outside of the ASG. Since the aircraft was already flying at the IM Speed cap of M0.84, no further speed-up IM Speeds could be provided to the crew that would have reduced the spacing at the achieve-by point.

Profiles of IM, Selected, and Actual KIAS Speeds during the descent and arrival are shown in Figure 4-27. The percent of time SEL was in conformance with the IM Speed during this period is shown in Figure 4-28. The time duration in minutes:seconds for each phase is shown below the phase name.

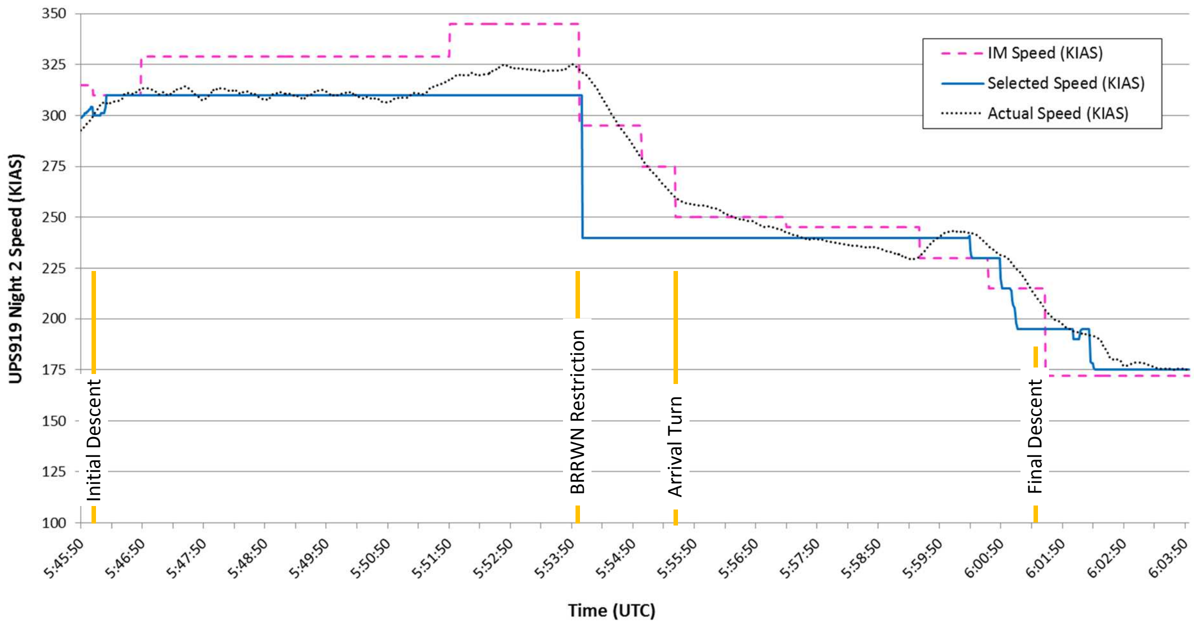


Figure 4-27. Night 2 UPS919 Speed Profile (KIAS)

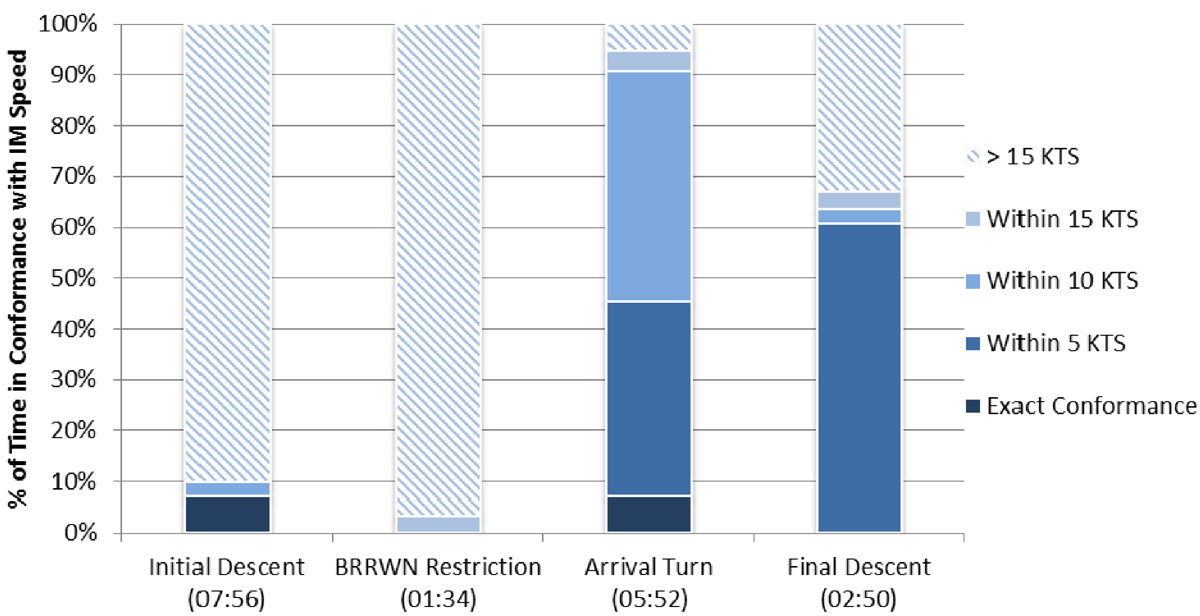


Figure 4-28. Night 2 UPS919 SEL Speed Conformance during Maintain Sub-Phases (KIAS)

Figure 4-27 suggests that at least during the BRRWN Restriction Phase, actual aircraft speed was in higher compliance than SEL. As such, it is possible that the crew may have used means other than SEL to comply with the IM Speeds. To further explore this, Figure 4-29 shows the percent of time actual aircraft speed was in conformance with the IM Speed across the Maintain sub-phases. The figure confirms that the BRRWN Restriction is the only phase where this is likely to have occurred.

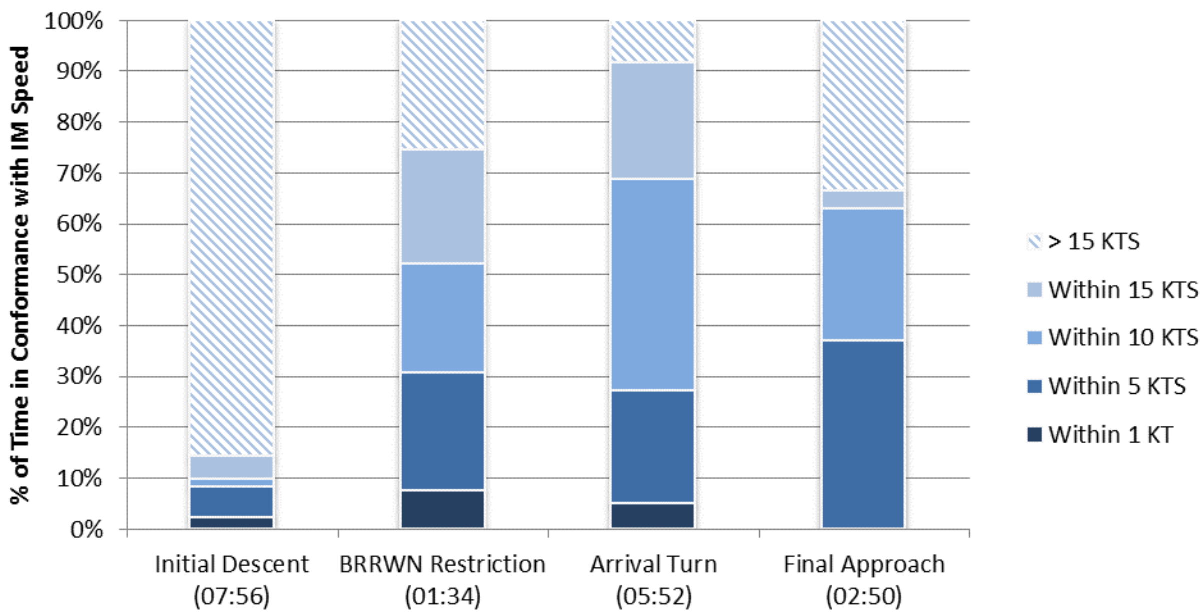


Figure 4-29. Night 2 UPS919 Actual Speed Conformance during Maintain Sub-Phases (KIAS)

In the early part of the Initial Descent Phase, the crew selected a speed-up IM Speed and began to close with its target. However, the crew did not select further speed-up IM Speeds and the observer noted that the crew appeared to still be using distance as the primary mechanism for spacing. After an IM Speed increase to 329 kts, the observer noted that the crew concluded that the IM Speeds "were not working" and that they would ignore them. However, since the spacing value was outside of the ASG, the IM Speed trend appears to be consistent with closing the gap. It is not clear what made the crew determine that the IM Speed values were not working, though it could be related to the IM Speeds not matching crew expectations before the IM-S AA period. This same crew flew UPS919 on Night 3 as well and noted that speed increases during descent were inappropriate. It is possible that this was also the reason they did not select the IM Speeds on Night 2, but it is unclear if this also meant that that they did not feel that the IM Speeds were appropriate to help them maintain the ASG. Whatever the reason, the crew showed low compliance and conformance for the rest of the phase.

An IM Speed trend change occurred when the IM Speed decreased 50 kts from its previous value three minutes before BRRWN. It is likely that this reduction was due to the lead aircraft slowing down. The crew response was to set SEL to the BRRWN SCR speed of 240 kts. Despite not stepping SEL down to match the IM Speed, Figure 4-29 shows that the actual aircraft speed had high conformance with the IM Speed reductions in the BRRWN Restriction Phase. The trend in the spacing value during this time seems to confirm this. Conformance during this phase, based on actual speed instead of SEL, was medium.

For most of the Arrival Turn Phase, the crew maintained a SEL speed lower than the IM Speed. Actual aircraft speed decreased to below both the SEL and IM Speed, though after JMCSY the IM Speed reduced to match the actual speed of 230 kts. After a short delay, the crew adjusted SEL to comply with this IM Speed and then a subsequent reduction to 215 kts. This helped bring spacing performance to within 1 sec of the ASG. Conformance during this phase, based on SEL, was medium.

Just before BRNBX, the crew elected to reduce speed further to 195 kts independent of the IM Speed. It is unclear exactly why the crew made this reduction, although it could be due to the flaps schedule. Not long after, the IM Speed reduced to 172 kts and the crew selected 175 kts in response. It is unclear why the crew did not comply exactly. At this point spacing was inside the ASG and decreasing.

Just before TGT TD and PARCL, the crew reduced speed again to 155 kts. This was 15 kts lower than the SCR at PARCL, although the actual speed was still 174 and within the allowable tolerance of the restriction, according to the procedure. A final IM Speed after that to 170 kts was not selected. Conformance during the Final Descent Phase was medium, although higher overall than in other phases as crews kept SEL within 5 kts of the IM Speed for more of the period.

Although SEL conformance during the BRRWN Restriction Phases was low, spacing performance was still close to the ASG due to higher conformance with actual aircraft speed. Despite the crew suggesting that they were not going to prioritize complying with IM Speeds, increased SEL and conformance during the Arrival Turn and Final Descent Phases appeared to help the crew maintain spacing performance close to the ASG. Final spacing when the Target Aircraft touched down was only 3 seconds inside of the ASG. A summary of overall conformance by phase is provided in Table 4-9. Conformance categorizations for each phase are based on SEL, except for BRRWN Restriction, which is based on aircraft actual speed. The spacing performance, IM Speeds, and crew-initiated changes for UPS919 Night 2 are provided in Figure 4-30.

Table 4-9. UPS919 Night 2 Speed Conformance Summary

Night	IM-S Flight	IM Speed Conformance	Spacing at Achieve-by Point Relative to ASG (sec)	IM Speed Conformance Spacing Mean (x) and Standard Deviation (SD) (Seconds, relative to ASG)				Average Maintain Spacing Relative to ASG (sec)	Spacing Relative to ASG at TGT TD (sec)
		Achieve		Initial Descent	BRRWN Restriction	Arrival Turn	Final Descent		
2	**UPS919**	**High**	**+22**	Low x = 14.5 SD = 1.1	Medium x = 13.8 SD = 0.2	Medium x = 7.6 SD = 3.2	Medium x = -1.4 SD = 1.3	**x = 9.7** **SD = 6.0**	**-3**

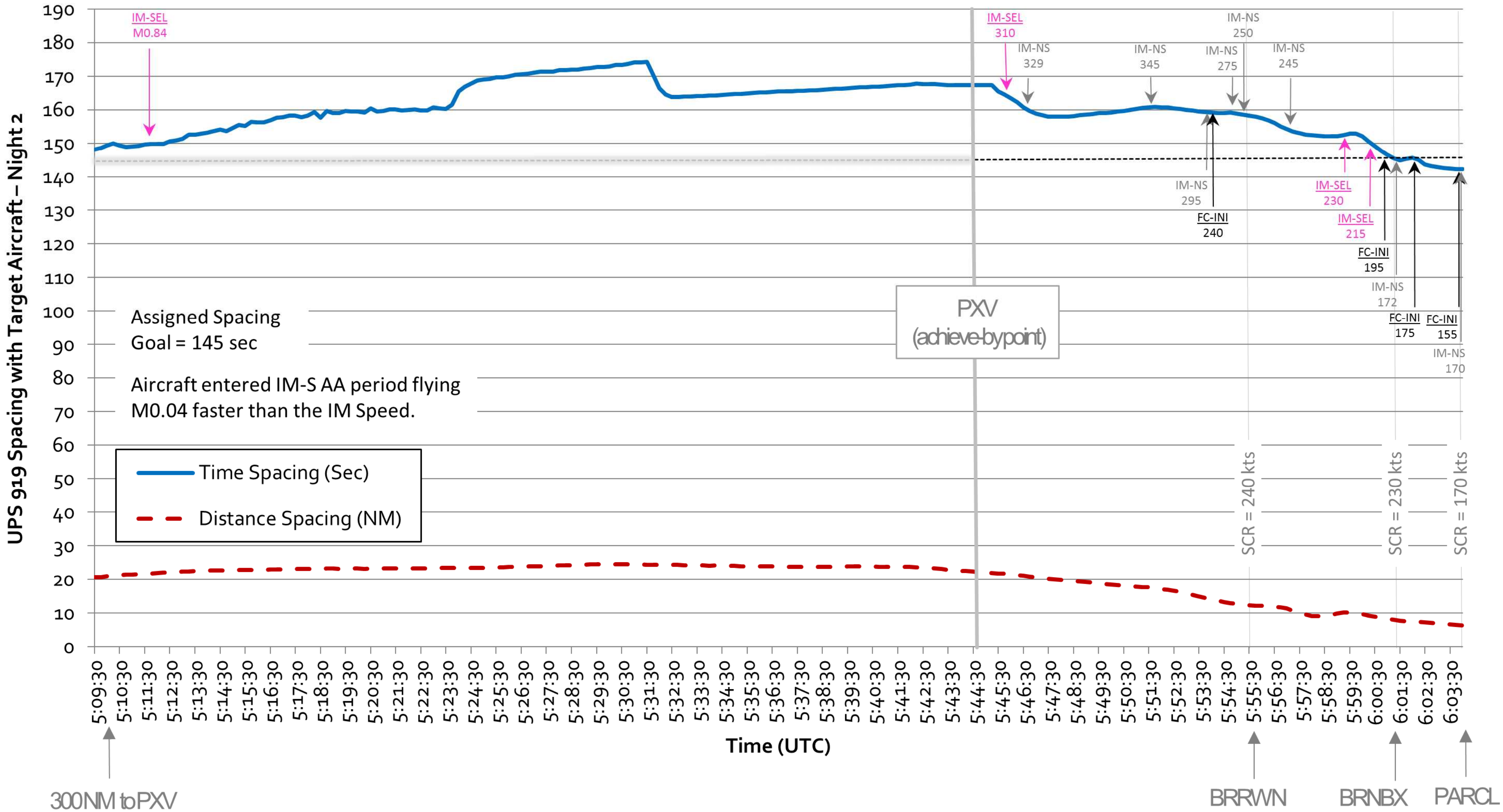


Figure 4-30. UPS919 Night 2 Spacing Performance

UPS919 → UPS903 → UPS905 → UPS857 → UPS921

Note: The cause of the "fin" shape in the spacing data starting at 05:23 is unknown. It does not appear to result from winds or Target Aircraft behavior, and may stem from a data recording anomaly.

4.2.10 Night 3 Sequence

Departure times were calculated and implemented by UPS to provide the best chance of successful airborne IM-S AA pairings. The aircraft departure sequence is shown in Table 4-10. An additional SafeRoute aircraft was available for Night 3 which allowed for a longer series.

Table 4-10. Night 3 Aircraft Departure Sequence

Flight ID	Departure Gateway and Wheels Up Time (UTC)
UPS921	SAN at 0229
UPS903	LAX at 0234
UPS905	LGB at 0239
UPS919	ONT at 0246
UPS857	PHX at 0301

Once in the air, initial setup was performed as described previously. Figure 4-31 shows the final aircraft sequence. Shortly after the achieve-by point, the crew of UPS919 declared that they were going to stop following the IM Speeds as they were uncomfortable accelerating during descent. As such, the following status of this aircraft is indicated by a grey arrow instead of black. Additionally, as noted in Table 2-7, on-board SafeRoute data collection was not available for UPS921, UPS857, and UPS905, so their spacing performance (calculated on-board) throughout the arrival is unknown. The narrative and other results from those flights are based on observer notes.

UPS919 → UPS905 → UPS903 → UPS857 → UPS921 → UPS957

Figure 4-31. Night 3 Final Aircraft Sequence

All IM-S AA aircraft arrived and landed on 35R at SDF via BRWWN CDA without ATC intervention. A graphic representation of the flight progression is provided in Appendix C.

4.2.11 UPS921 Night 3 Flight Summary

Profiles of IM, Selected, and Actual KIAS Speeds for UPS921 are shown in Figure 4-32. SafeRoute data was unavailable for this flight on Night 3, so crew actions and speed behavior are derived from observer notes.

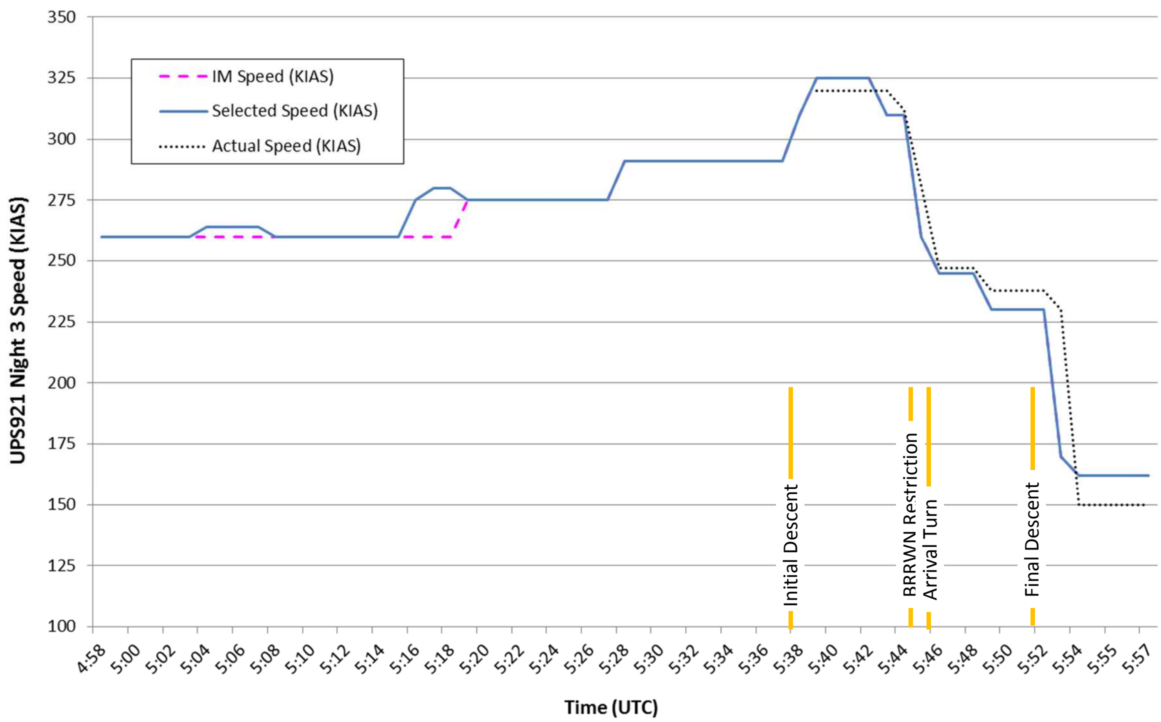


Figure 4-32. Night 3 UPS921 Speed Profile (KIAS)

The flight appeared to enter the IM-S AA period flying 10 kts faster than the IM Speed. The observer noted that the crew increased speed as they "were not catching up to their lead [aircraft]." Approximately 300 NM from PXV, and at the start of the Achieve Phase, the crew reinitialized the system and received an IM Speed of 260 kts. The observer reports they complied. After this, however, four relatively brief occurrences of crew-initiated speed changes were reported. The observer did not note why, but based on the range to target reports, it appears likely that the crew was increasing speed to close the distance with the Target aircraft.

The crew then selected the next several speed-up IM Speeds, which brought them into the initial descent. An IM Speed trend change occurred shortly before BRRWN, as the IM Speeds decreased in response to the lead aircraft slowing down. The observer noted no SEL speeds that deviated from the IM Speeds through this reduction.

At BRNBX, the crew selected the IM Speed which was equal to the SCR. At UPSCO, the crew selected the IM Speed which was 40 kts higher than the SCR. After UPSCO, the observer reported no lack of crew compliance with the final two IM Speeds. Spacing performance and IM Speed response time results are not available for this flight due to the lack of detailed SafeRoute data.

4.2.12 UPS857 Night 3 Flight Summary

Profiles of IM, Selected, and Actual KIAS Speeds for UPS857 are shown in Figure 4-33. SafeRoute data was unavailable for this flight on Night 3, so crew actions and IM Speed behavior is derived from observer notes. Actual aircraft speed was available from Night 3 UPS903 Target Aircraft data.

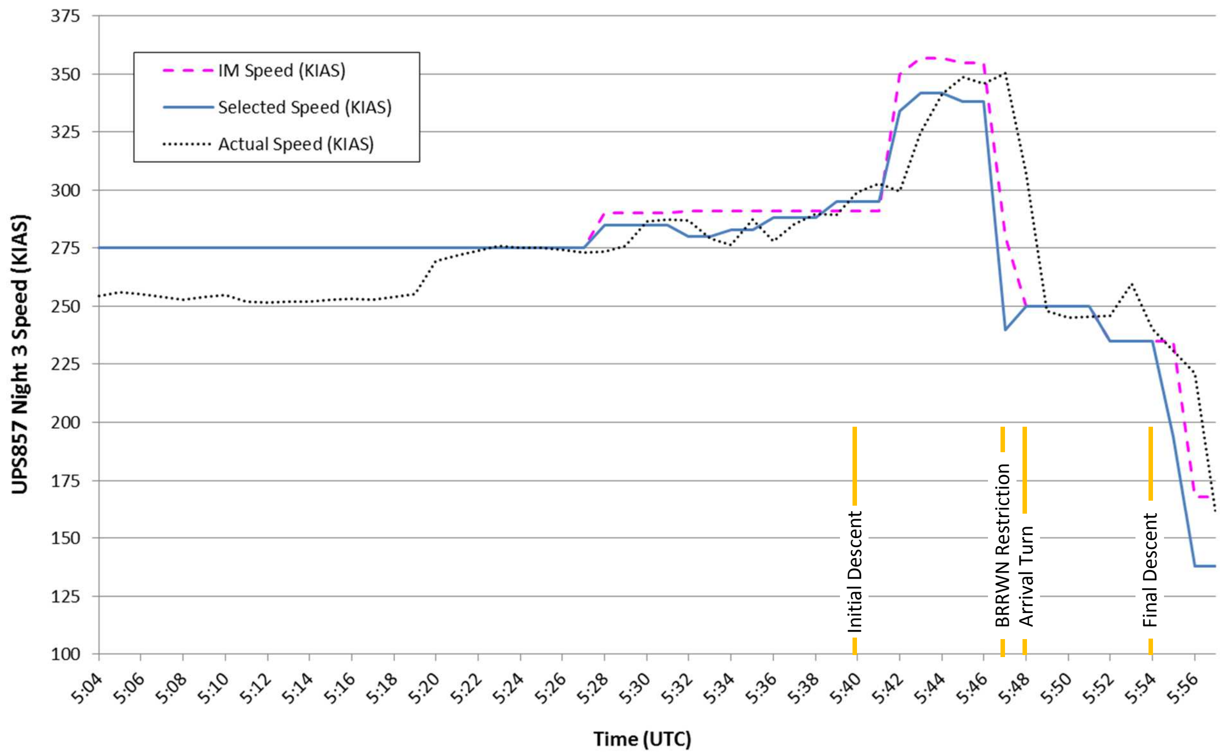


Figure 4-33. Night 3 UPS857 Speed Profile (KIAS)

At the beginning of the IM-S AA period, the crew appeared to be in conformance with the IM Speed value. The exact reason for the discrepancy between SEL and actual aircraft speed for the first 15 minutes of the Achieve period is unknown, though possibly due to the observer not recording SEL changes during this period. During the Achieve Phase, the crew responded to IM Speed values of 290 and 291 kts by instead selecting speeds between 280 and 288 kts. It is unlikely that the IM Speed values were close to aircraft limits since: 1) the crew selected 295 kts just before the merge fix and, 2) many of the other flights maintained speeds faster than 290 kts during this phase. As such, it is unclear exactly why the crew did not comply exactly with the IM Speeds.

The trend of the IM Speeds during the Achieve and Initial Descent Phases was to increase aircraft speed. Just after the achieve-by point, the IM Speed increased from 291 to 350 kts. Shortly after, it increased again to 357 kts then decreased to 355 kts. In response, the crew increased speed to 334 kts, then 342 kts, but went no further. In their pilot questionnaire, the crew noted "numerous commands to M_{MO}"; it seems likely they were referring to their experience in this phase. Throughout this phase, the crew selected speeds that were approximately 15 kts slower than the IM Speeds. The IM Speed trend changed just before BRRWN and suggested a slower IM Speed.

Instead of complying, the crew input 240 kts directly. Despite the breakpoint at 280 kts that the crew did not dial in, this phase shows good conformance with respect to actual speed. The fact that the crew initially selected 240 kts and corrected to 250 kts when the IM Speed showed that value confirms the intent to match the Target Aircraft's deceleration.

The crew then selected the two IM Speeds between BRRWN and JMCSY, even though the first resulted in a 10 kt speed increase of SEL (but was still slower than the previous IM Speed). At BRNBX, the crew was in compliance with an IM Speed that was still within the limits as defined by the CDA procedure. At UPSCO, however, the IM Speed was 45 kts greater than the SCR and the crew appeared to select a speed 4 kts faster than the speed restriction value. At PARCL the IM Speed was 2 kts less than the restriction. However, the crew reduced further to what was likely their FAS. Conformance appeared high overall until FAS was selected. Spacing performance and IM Speed response time results are not available for this flight due to the lack of detailed SafeRoute data.

4.2.13 UPS903 Night 3 Flight Summary

On Night 3, the crew of UPS 903 appeared to fly KIAS for the entire Achieve Phase. Therefore, profiles of IM, Selected, and Actual Speeds for UPS903 during the IM-S AA Achieve Phase are summarized in Figure 4-34.

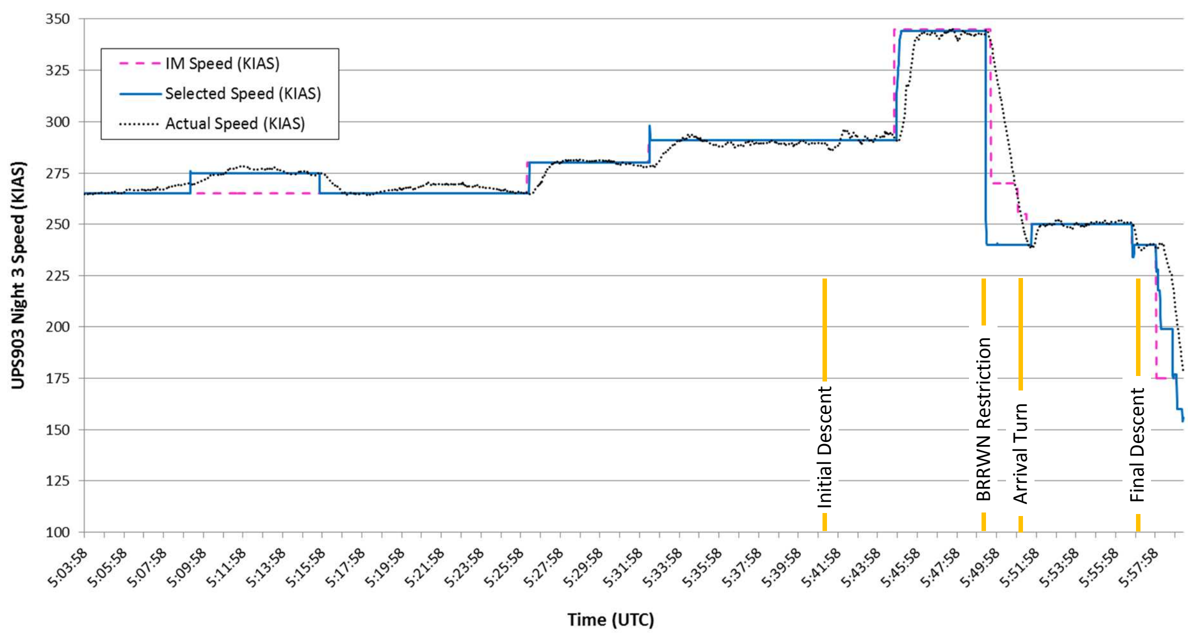


Figure 4-34. Night 3 UPS903 Speed Profile (KIAS)

UPS903 entered the IM-S AA period flying the IM Speed received before the Achieve Phase. Spacing was over a minute outside of the ASG and closing. The crew then initiated two independent speed changes: one to speed up, the other to slow down and return to the IM Speed value. Spacing continued to close and two further speed-up IM Speeds were provided. The crew selected both. With high overall conformance during the majority of the Achieve Phase, UPS903 was 6 seconds outside of the ASG at the achieve-by point. The percent of time SEL was in conformance with the IM Speed is shown in Figure 4-35. The time duration in minutes:seconds for each phase is shown below the phase name.

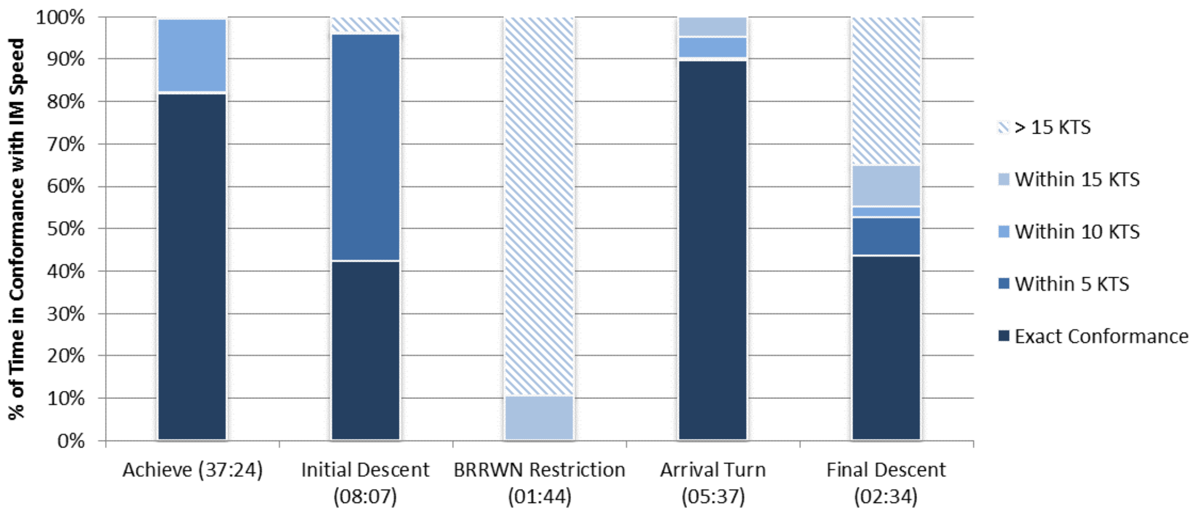


Figure 4-35. Night 3 UPS903 SEL Speed Conformance (KIAS)

Spacing throughout the descent was relatively stable and remained within approximately 8 seconds of the ASG. During the Initial Descent Phase, the IM Speed increased to 345 kts and the crew responded with a SEL of 344 kts. Since the maximum allowable speed at this point was 357 kts, as determined by the Air Data Computer (ADC) and recorded in SafeRoute data, it is unclear why the crew did not conform exactly to the IM Speed. The trend of the IM Speeds during the Achieve and Initial Descent Phases was to increase aircraft speed and overall crew conformance was high. Before BRRWN, the IM Speed trend changed and suggested a slower IM Speed. However, shortly before the IM Speed began decreasing, the crew input 240 kts to comply with the BRRWN SCR.

In the BRRWN Restriction Phase, the crew maintained 240 kts in the MCP while the IM Speed stepped down. When the IM Speed reached 250 kts, just after BRRWN, the crew complied. The fact that the crew initially selected 240 KIAS and corrected to 250 KIAS when the IM Speed settled on that value confirms the overall intent to match the Target Aircraft's deceleration and follow the IM Speeds. Despite this, an examination of actual aircraft speed during this phase showed a greater than 15 kts difference between the IM Speed and actual aircraft speed more than 50% of the time. As such, IM Speed conformance is still considered low for this phase.

Conformance during the Arrival Turn Phase was high, with the crew selecting the two IM Speeds. In the Final Descent Phase just before UPSCO, however, an IM Speed was presented that was 15 kts slower than the SCR. The crew reduced to 199 shortly after UPSCO. They then stepped SEL down to the IM Speed, which may have been due to the flap extension schedule. Conformance is rated as medium for this phase as SEL was within 10 kts of the IM Speed for more than 50% of the period.

The final spacing was 8 seconds inside of the ASG when the Target aircraft touched down. A summary of overall conformance by phase is provided in Table 4-11. The spacing performance, IM Speeds, and crew-initiated changes for UPS903 Night 3 are provided in Figure 4-36.

Table 4-11. UPS903 Night 3 Speed Conformance Summary

Night	IM-S Flight	IM Speed Conformance	Spacing at Achieve-by Point Relative to ASG (sec)	IM Speed Conformance Spacing Mean (x) and Standard Deviation (SD) (Seconds, relative to ASG)				Average Maintain Spacing Relative to ASG (sec)	Spacing Relative to ASG at TGT TD (sec)
		Achieve		Initial Descent	BRRWN Restriction	Arrival Turn	Final Descent		
3	**UPS903**	**High**	**+6**	**High** x = 5.3 SD = 1.3	**Low** x = 2.6 SD = 0.6	**High** x = 5.4 SD = 0.9	Medium x = -0.8 SD = 3.1	**x = 4.2** **SD = 2.7**	**-8**

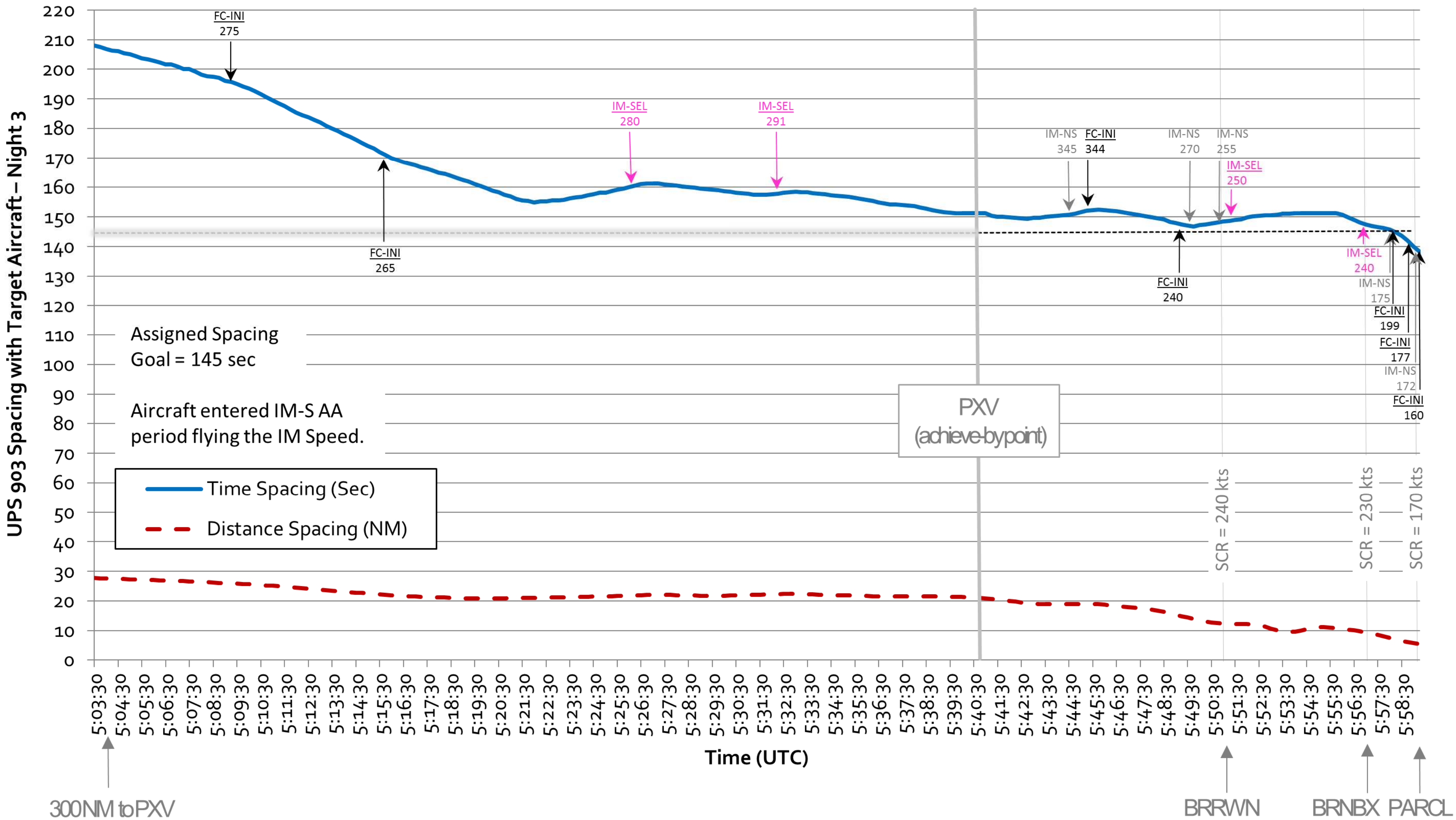


Figure 4-36. UPS903 Night 3 Spacing Performance

UPS919 → UPS905 → **UPS903** → UPS857 → UPS921 → UPS957

4.2.14 UPS905 Night 3 Flight Summary

Profiles of IM, Selected, and Actual KIAS Speeds for UPS857 are shown in Figure 4-37. SafeRoute data was unavailable for this flight on Night 3, so crew actions and IM Speed behavior are derived from observer notes. Actual aircraft speed is taken from Night 3 UPS919 SafeRoute Target Aircraft data.

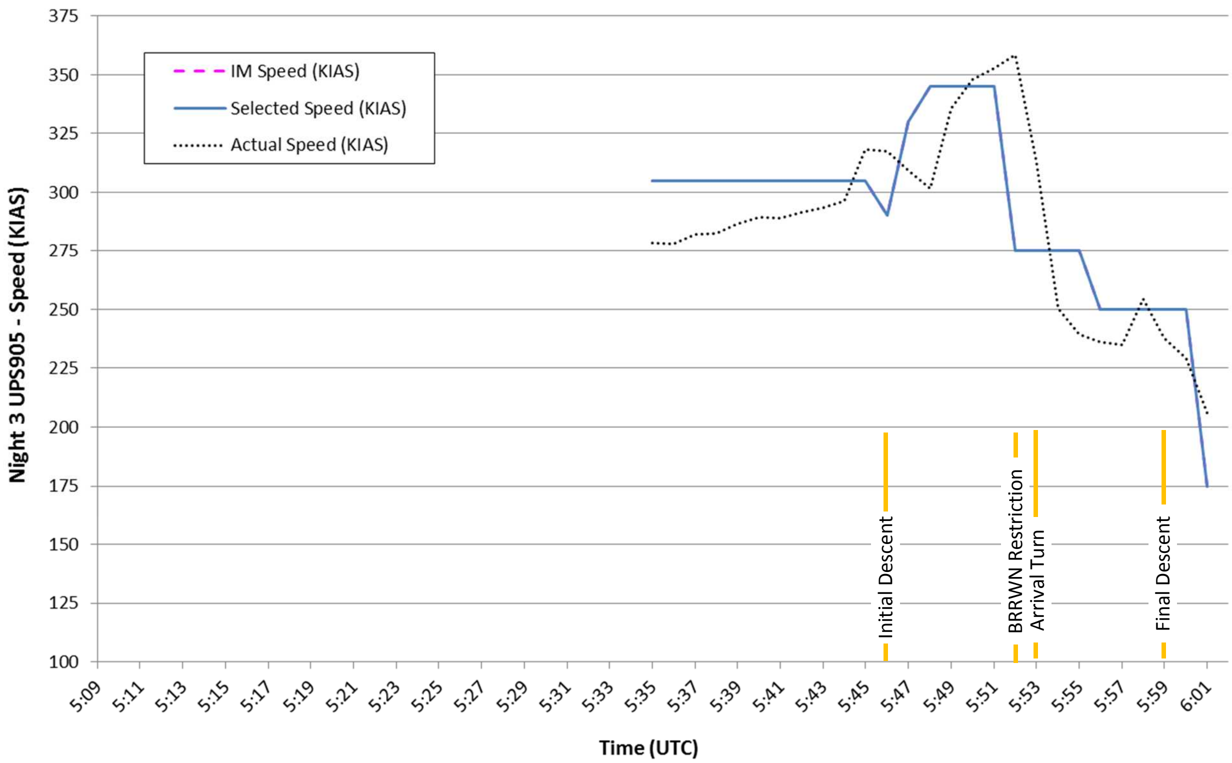


Figure 4-37. Night 3 UPS905 Speed Profile (KIAS)

The observer noted only one IM Speed during the Achieve period. There was no indication that the crew did not comply with it. No instances of crew-initiated speed changes any time during the flight were noted.

The first of two IM Speed trend changes occurred just after the achieve-by point and resulted from a change in the IM Speed trends from decreasing to increasing. A second IM Speed trend change occurred during the descent and resulted from the IM Speed trend switching to decreasing SEL. However, as the detailed SafeRoute data is not available for this flight, the analysis is unable to determine how these trend changes related to the spacing interval.

At BRNBX, the crew selected the IM Speed, which was 20 kts higher than the SCR. No speed reductions were noted before UPSCO, suggesting that the IM Speed and SEL were 60 kts higher than the SCR. After UPSCO, the IM Speed reduced to 5 kts above the SCR at PARCL and the crew appears to have complied. Spacing performance and IM Speed response time results are not available for this flight due to the lack of detailed SafeRoute data.

4.2.15 UPS919 Night 3 Flight Summary

Profiles of IM, Selected, and Actual Mach Speeds for UPS919 during the IM-S AA Achieve Phase are summarized in Figure 4-38. UPS919 on Night 3 had the same crew as UPS919 on Night 2. The flight entered the IM-S AA period approximately 20 seconds inside the ASG and flying M0.01 slower than the IM Speed of M0.83. After three crew-initiated, slow-down speed changes early in the Achieve period, the IM Speed decreased from its previous value, but to a level still higher than the crew-initiated SEL. The crew complied shortly after and remained in conformance for the rest of the Achieve Phase.

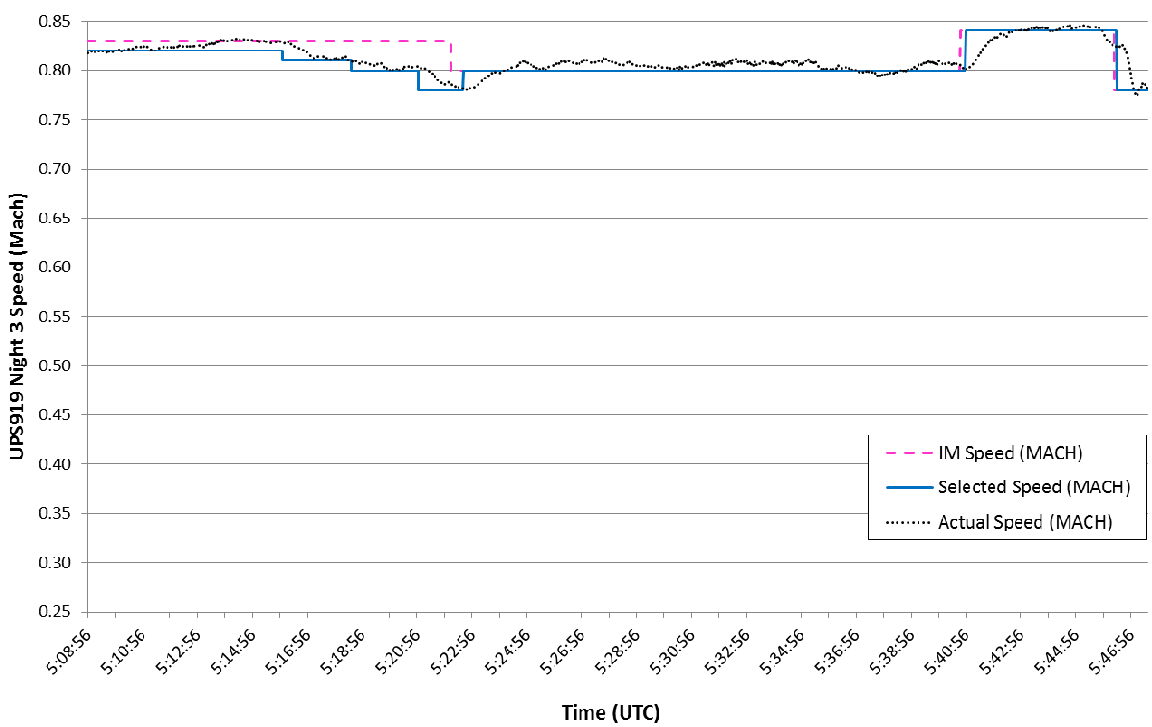


Figure 4-38. Night 3 UPS919 Speed Profile (MACH)

Shortly before Initial Descent, spacing started to open up and the IM Speed commanded a speed-up. The crew selected the IM Speed and crossed the achieve-by point with a spacing 5 seconds outside of the ASG. An IM Speed trend change occurred just after the achieve-by point and resulted from a change in the IM Speed trends from increasing to decreasing aircraft SEL. The crew selected the IM Speed.

Profiles of IM, Selected, and Actual KIAS Speeds during the descent and arrival are shown in Figure 4-39. The percent of time SEL was in conformance with the IM Speed during this period is shown in Figure 4-40. The time duration in minutes:seconds for each phase is shown below the phase name.

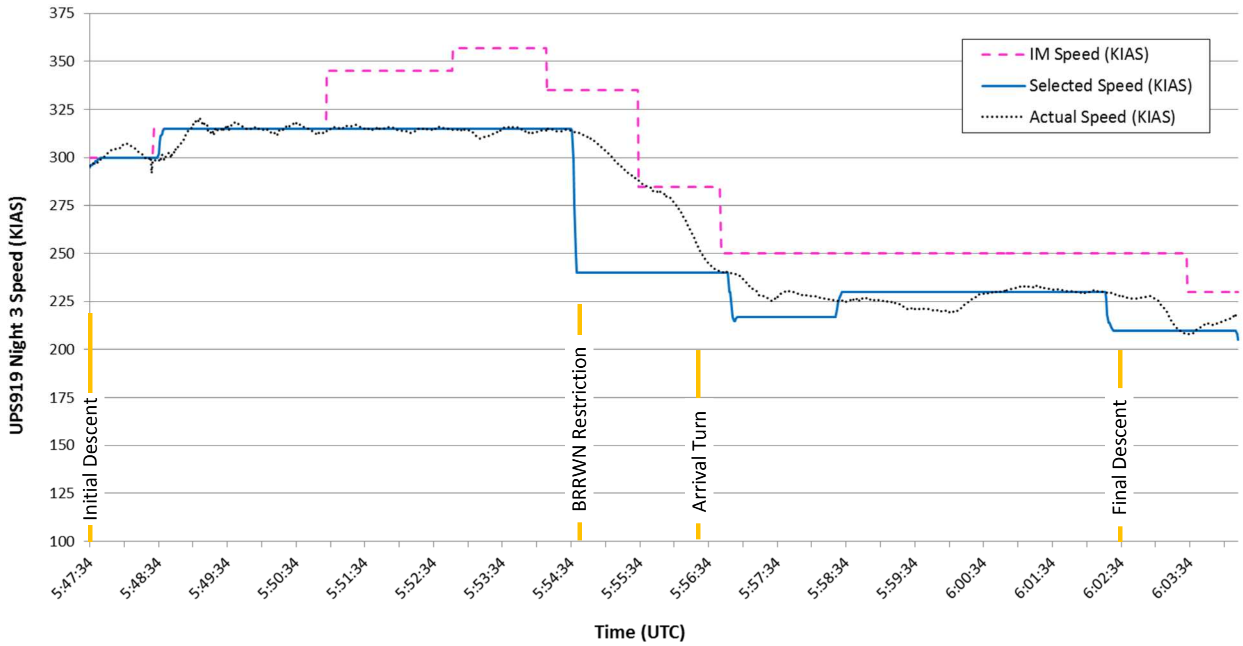


Figure 4-39. Night 3 UPS919 Speed Profile (KIAS)

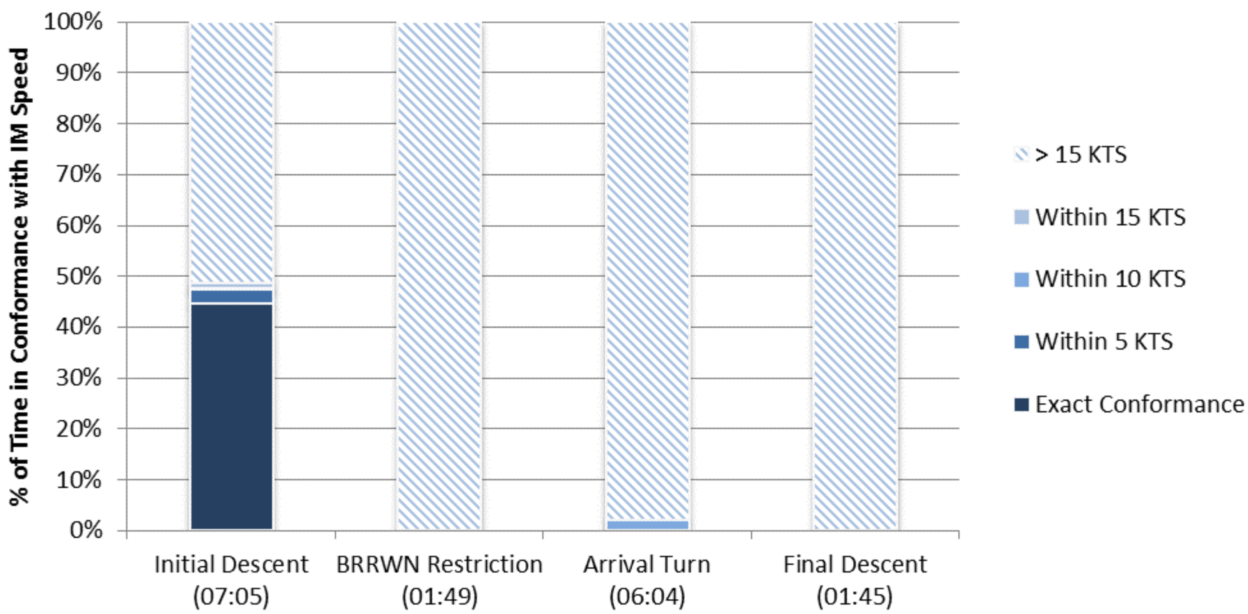


Figure 4-40. Night 3 UPS919 SEL Speed Conformance during Maintain Sub-Phases (KIAS)

The crew selected the two IM Speeds during the first few minutes of the descent. However, their time spacing with the Target Aircraft began to increase and the IM Speeds continued to increase

– ultimately to 357 kts. The crew elected not to comply as they noted to the observer that they did not feel it was appropriate to significantly accelerate after TOD – especially with a large magnitude speed-up that they reported would have brought them close to V_{MO}.

The trend of the IM Speeds during the Initial Descent Phase was to maintain a higher aircraft speed than what was selected. Before BRRWN, and before the IM Speed began decreasing, the crew input 240 kts to comply with the BRRWN SCR. The crew did not select the stepping-down IM Speeds and maintained a 240 kt SEL, though the actual speed at one point matched the IM Speed. When the IM Speed reached 250 kts in the Arrival Turn Phase, the crew elected to decrease speed to 217 kts, though they later slightly increased it.

At BRNBX the IM Speed was 20 kts greater than the SCR. The crew selected and maintained a speed 20 kts slower than the restriction. At UPSCO the IM Speed was 40 kts greater than the SCR. The crew continued to maintain their previous speed and crossed UPSCO nearly 20 kts faster than the restriction. Since overall spacing was well outside of the ASG, the Target Aircraft touched down just after UPS919 crossed UPSCO. This resulted in a relatively short Final Descent period as compared to the other flights. Conformance was low since the SEL and actual aircraft speed was consistently 20 – 40 kts slower than the IM Speeds. Final spacing when the Target Aircraft touched down was 49 seconds outside of the ASG, the greatest difference of all the flights.

Overall, the crew appeared to place a low priority on IM Speed conformance during the Maintain portion of the flight. The reason for the loss of spacing that resulted in the speed-up IM Speeds is unclear, though it could possibly be due to the behavior of its Target Aircraft. The crew noted that the AGD commanded the “maximum” speed even they were less than 20 miles from the Target Aircraft at TOD. The crew further explained that they lost spacing because the Target Aircraft (UPS905) kept up “its speed up during the descent and was not at 240 IAS when it passed the first waypoint.” This appears to be consistent with the UPS905 Night 3 speed profile (Figure 4-37); however SafeRoute data was not available for that flight, precluding further investigation into the cause.

A summary of overall conformance by phase is provided in Table 4-12. The spacing performance, IM Speeds, and crew-initiated changes for UPS919 Night 3 are provided in Figure 4-41.

Table 4-12. UPS919 Night 3 Speed Conformance Summary

Night	IM-S Flight	IM Speed Conformance	Spacing at Achieve-by Point Relative to ASG (sec)	IM Speed Conformance Spacing Mean (x) and Standard Deviation (SD) (Seconds, relative to ASG)				Average Maintain Spacing Relative to ASG (sec)	Spacing Relative to ASG at TGT TD (sec)
		Achieve		Initial Descent	BRRWN Restriction	Arrival Turn	Final Descent		
3	UPS919	Medium	+4	Low x = 8.9 SD = 4.3	Low x = 24.5 SD = 2.5	Low x = 38.6 SD = 7.0	Low x = 48.8 SD = 0.4	x = 25.6 SD = 16.2	+49

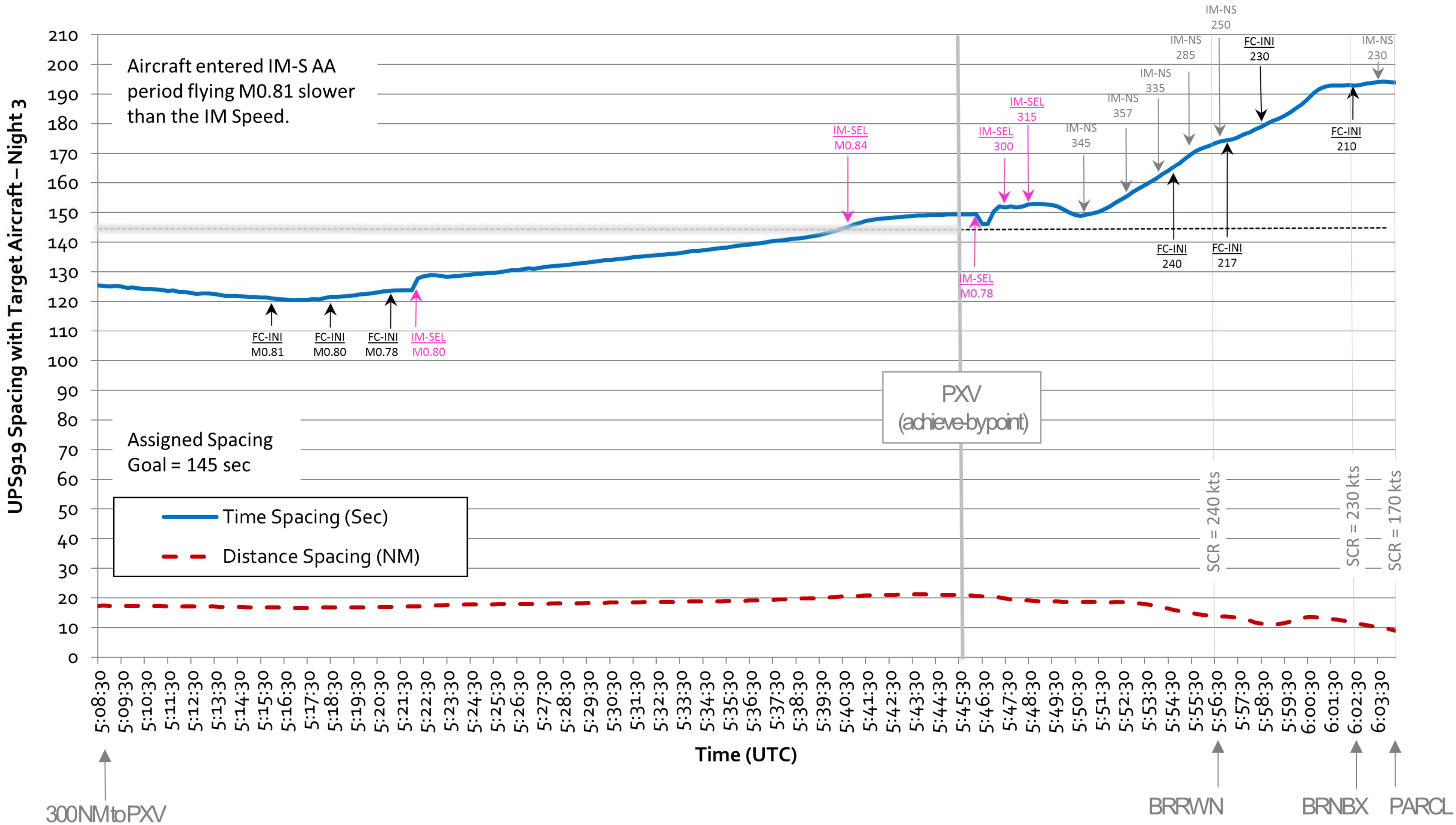


Figure 4-41. UPS919 Night 3 Spacing Performance

UPS919 → UPS905 → UPS903 → UPS857 → UPS921 → UPS957

4.3 Spacing Performance Summary

Figure 4-42 presents the spacing performance results from each of the flights with available SafeRoute data (n=8) referenced to the time remaining in minutes (min) to cross the FAF (PARCL). As shown in the figure, most flights were within +/- 5 seconds of the ASG by PARCL, with the exception of UPS905 on Night 2 and UPS919 on Night 3. Both of these flights exhibited particularly low conformance with IM Speeds during the descent and arrival.

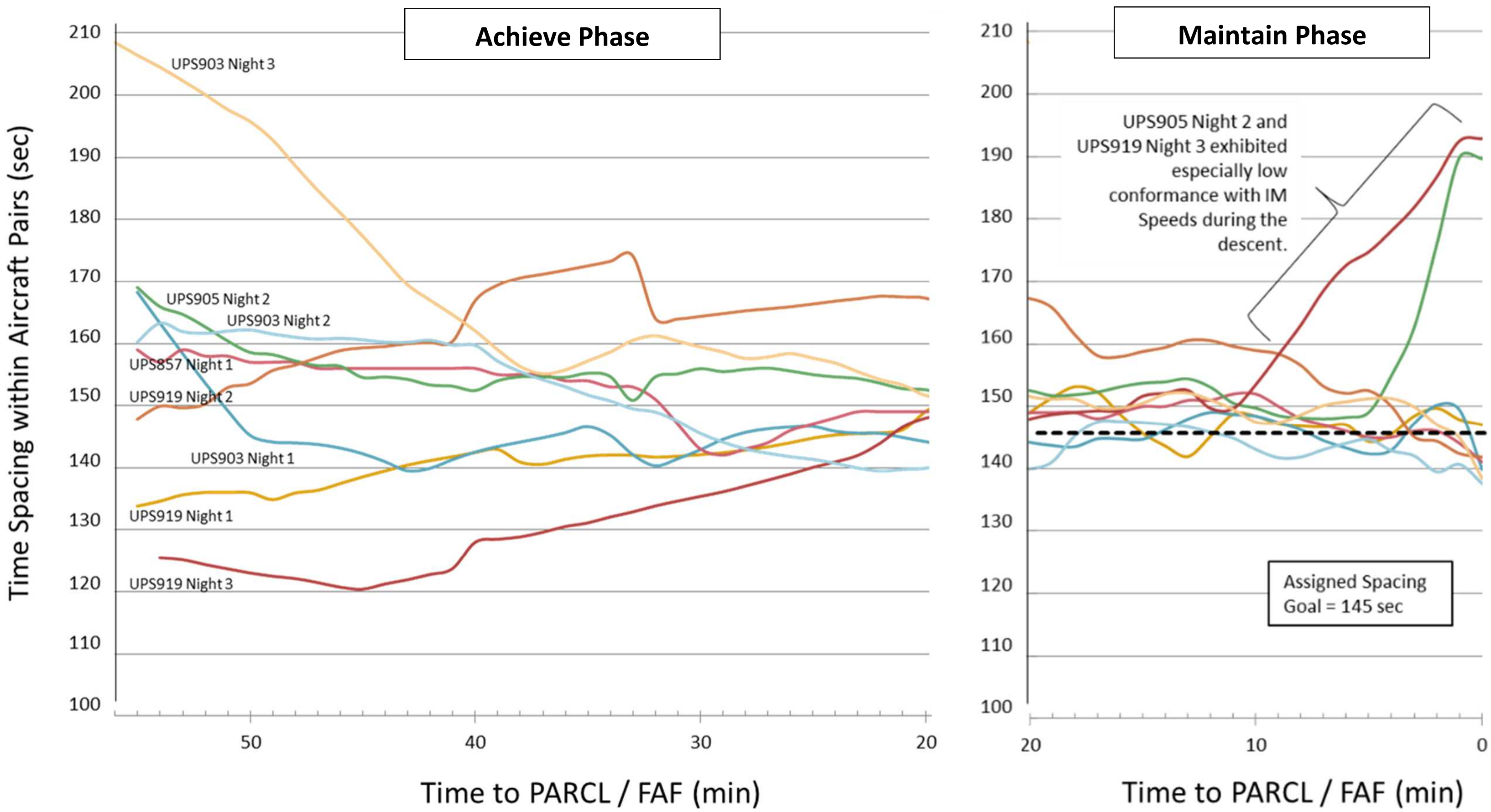


Figure 4-42. Time Spacing Performance for the Achieve and Maintain Phases: Nights 1-3

4.4 IM Speed Compliance and Conformance by Arrival Phase

The following sections summarize IM Speed Compliance and Conformance by operational phase and overall. The compliance analyses classify IM Speeds as either Selected, Already Selected, or Not Selected. For the most part, compliance and conformance were determined by crew SEL response to the IM Speed. However, in some cases, crews may have tried to control aircraft speed to comply with or conform to the IM Speeds through other means. These occurrences were noted in Section 4.2 and also considered here when appropriate.

For the conformance analyses, the percentage of time SEL (Mach and KIAS) on the MCP was in conformance with the IM Speed over the course of the IM-S AA period was derived from SafeRoute data and observer reports. Figure 4-1 provided an explanation for the IM Speed conformance graphics. Although the explanation is for KIAS conformance, Mach conformance results figures should be interpreted the same way. Mach data for some flights are not included because they appeared to stay in KIAS mode from the beginning of the IM-S AA period.

The average total number of IM Speeds per flight over the entire IM-S AA period was 11 (Standard Deviation = 2.7). The most received was 16 and the fewest received was 7. The average number of IM Speeds not selected per flight was 4 (Standard Deviation = 2.8). However, since not selected IM Speeds could only be inferred in a limited number of cases from observer notes for flights where SafeRoute data was not available, this average may be lower than what actually occurred. There were only four Already Selected occurrences; however, this could also be low due to the lack of precision in the flights where SafeRoute data was not available.

4.4.1 Achieve

The Achieve Phase consisted of the 300 NM segment that defined the start if the IM-S AA period through the achieve-by point (PXV). Most flights maintained a cruse altitude at FL350 and had a TOD within close proximity of PXV. Although most flights flew Mach speeds through the TOD point, some transitioned early to KIAS. These included UPS857 and UPS903 on Night 2 and UPS921, UPS857, UPS903, and UPS905 on Night 3. Figure 4-43 shows the number of IM Speeds each flight received in the Achieve Phase and the crew response.

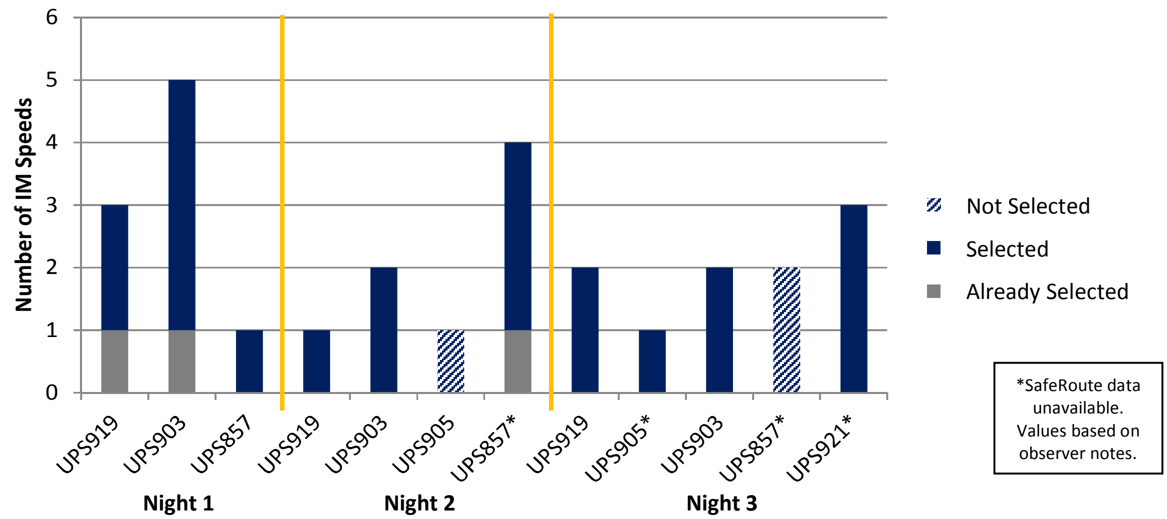


Figure 4-43. IM Speed Compliance (SEL) – Achieve Phase

Figure 4-44 shows the percentage of time the SEL on the MCP was in conformance with the IM Speed during the Achieve Phase for both Mach and KIAS.

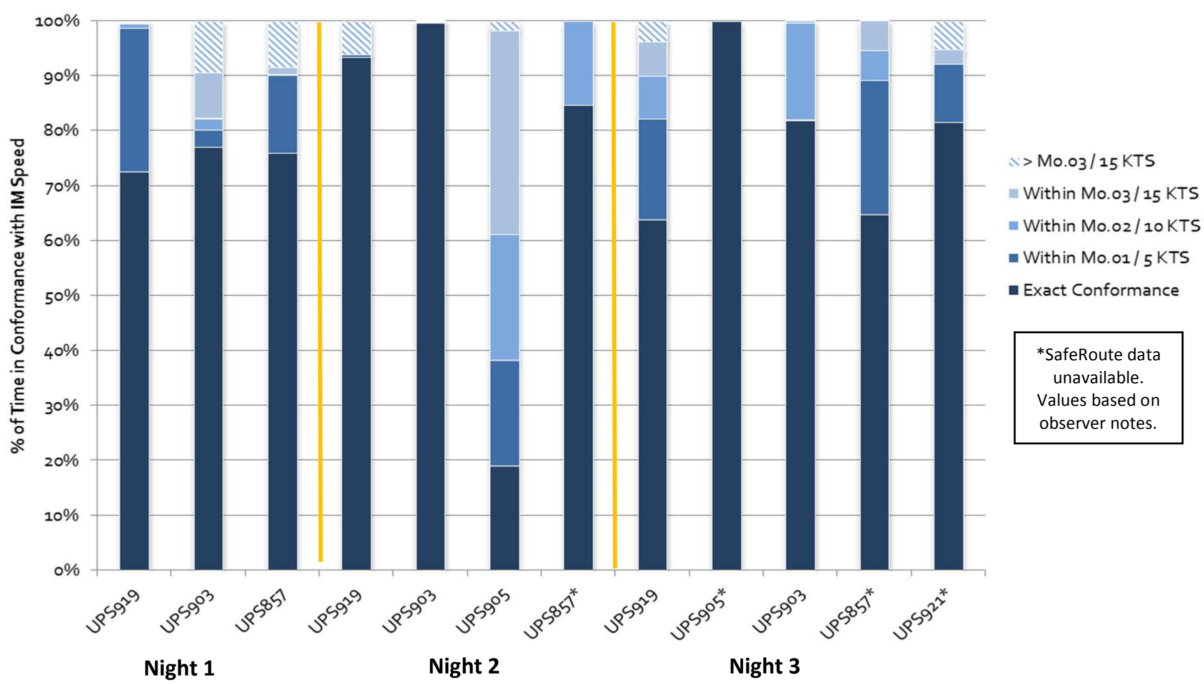


Figure 4-44. IM Speed Conformance (SEL) – Achieve

Relatively few IM Speeds were provided in the Achieve Phase and most were selected overall. As shown in Figure 4-43, UPS905 on Night 2 and UPS857 on Night 3 showed the only cases of not selecting IM Speeds. (UPS905 showed high Achieve Phase conformance as it entered the IM-S AA period already in compliance with an IM Speed.) Also, Figure 4-44 shows that the other flights were either in either exact or close conformance with the IM Speeds for 80% or more of the phase.

Across the flights, overall conformance is consistent with compliance. The ten flights that showed high compliance in following the IM Speeds had SEL within +/- 0.01M or 5 kts of the IM Speed for at least 70% of the phase.

4.4.2 Maintain: Overall

Figure 4-45 shows the number of IM Speeds each flight received across the Maintain Phase and the crew response.

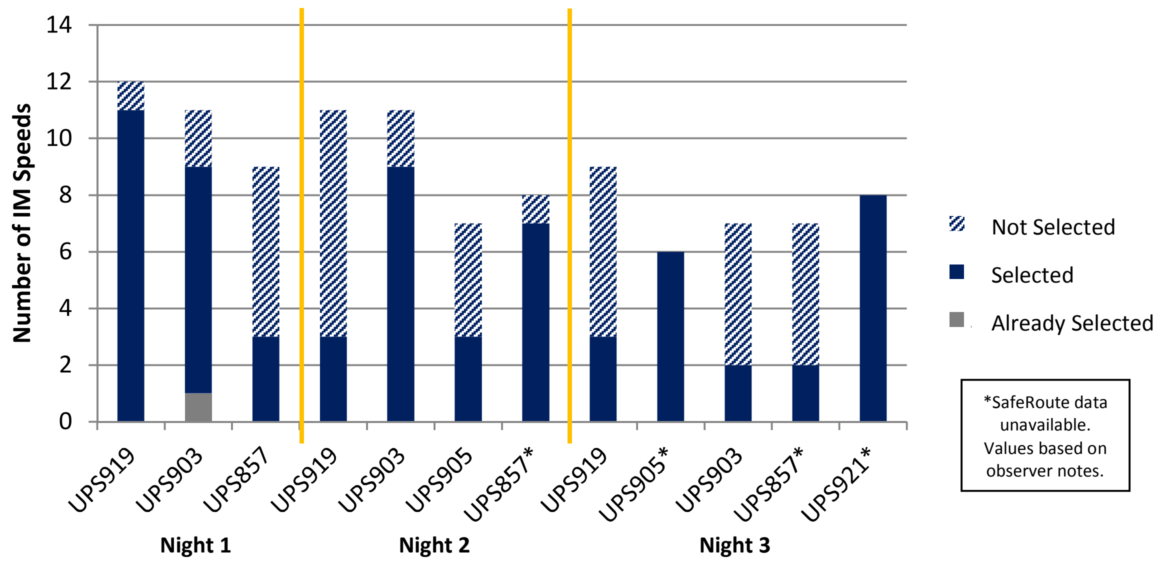


Figure 4-45. IM Speed Compliance (SEL) – Maintain Phase

Figure 4-46 shows the percentage of time the SEL on the MCP was in conformance with the IM Speed during the Maintain Phase.

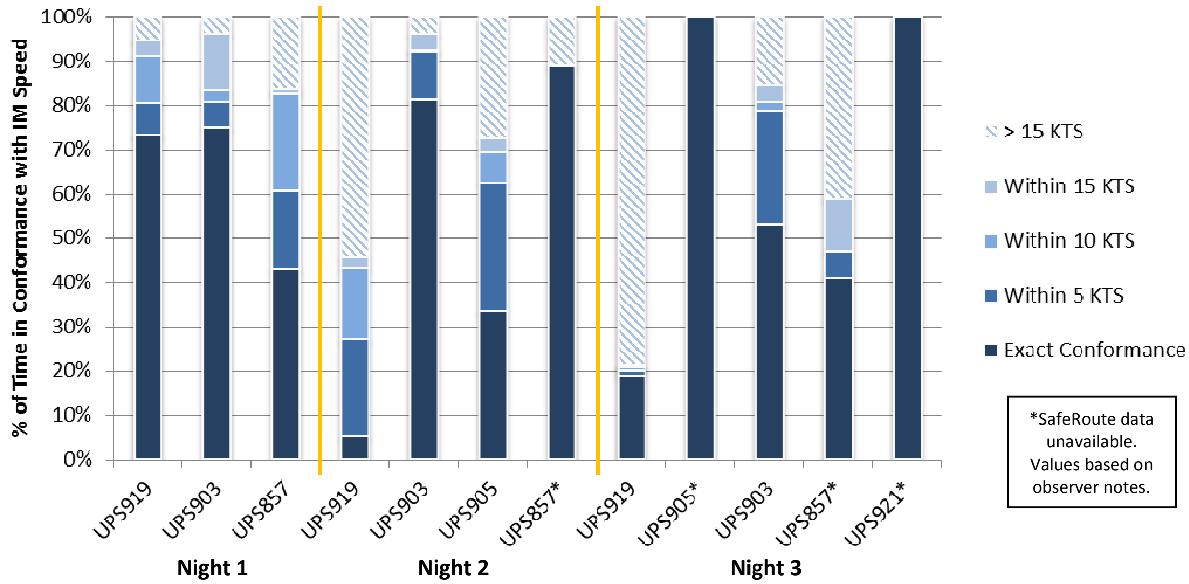


Figure 4-46. IM Speed Conformance (SEL) – Maintain

Crews experienced the majority of the IM Speeds in the Maintain Phase. With a couple of exceptions, IM Speed compliance and conformance are generally consistent. However, flights with similar overall levels of conformance, such as UPS857 Night 1 and UPS905 Night 2, had different final spacing results. As such, variances in IM Speed conformance at different times during the Maintain Phase can affect the final spacings. To explore this further, compliance and conformance across the aircraft for each of the Maintain sub-phases are explored in the following sections.

4.4.3 Maintain: Initial Descent

As shown in Figure 4-2, the Initial Descent Phase started just *after* the achieve-by point and ended just *before* the deceleration to meet the BRRWN SCR. This included either an IM Speed that was less than 300 KIAS, or when the crew initiated a SEL speed change that was less than 300 KIAS – whichever came first. The phase consisted of a straight segment where aircraft began their descent from FL350. Ending altitudes varied, depending on when the speed change occurred. However, it never went beyond BRRWN which had an 11,000 ft. altitude restriction in place. Figure 4-47 shows the number of IM Speeds each flight received in the Initial Descent Phase and how crews complied.

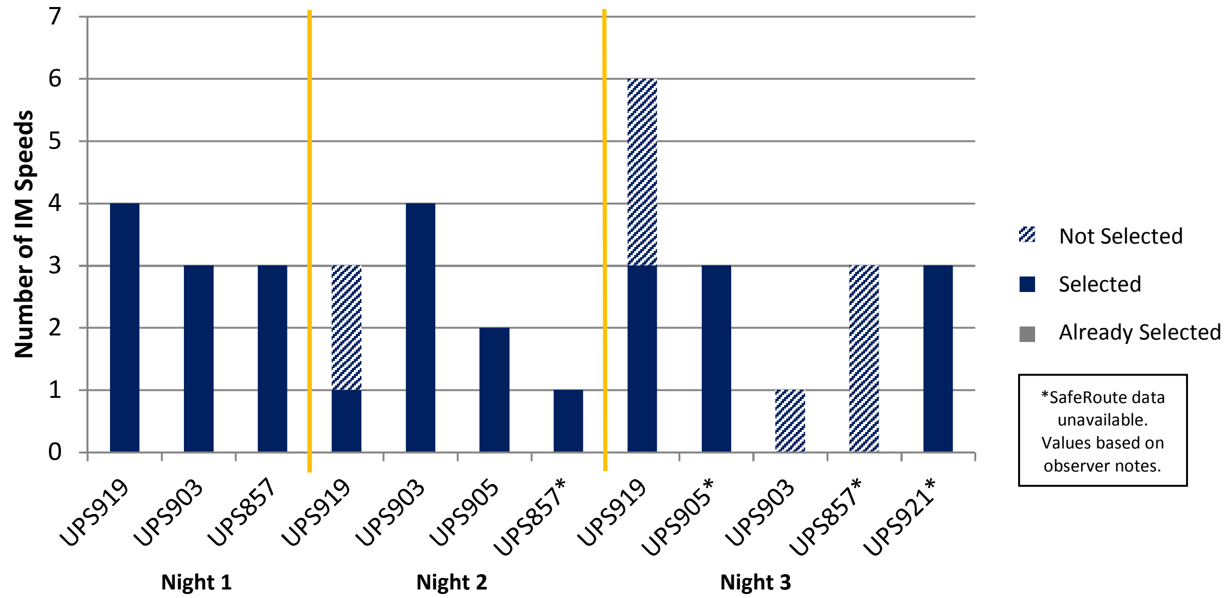


Figure 4-47. IM Speed Compliance (SEL) – Initial Descent

Figure 4-48 shows the percentage of time the selected speed value on the MCP was in conformance with the IM Speed during the Initial Descent Phase.

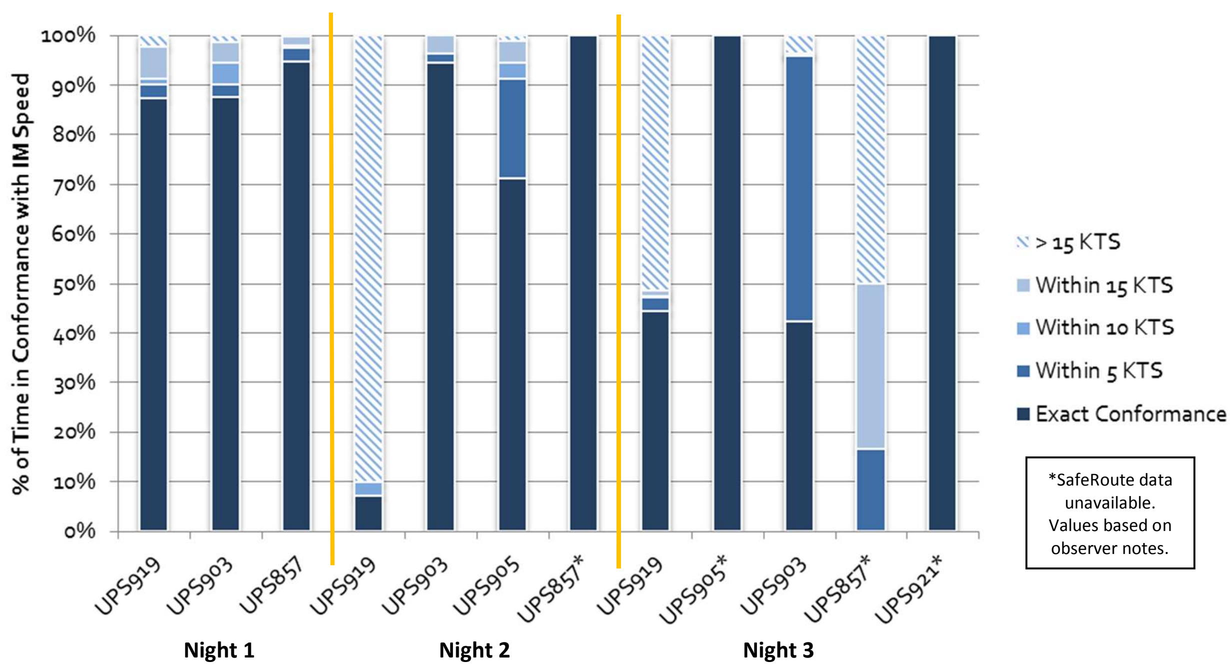


Figure 4-48. IM Speed Conformance (SEL) – Initial Descent

As shown in Figure 4-47, most flights showed high compliance with the IM Speeds during Initial Descent. Four flights, however, did not select IM Speeds as they began their descent and three of these also showed low conformance. UPS919 on Nights 2 and 3 shared the same crew which noted the same reasons for not selecting the IM Speeds during the initial part of the descent. As described in Sections 4.2.9 and 4.2.15, the crew did not feel it was appropriate to increase speed during descent, thus they did not select the speed-up IM Speeds that attempted to close the spacing gaps with the Target Aircraft. UPS919 showed on Night 3 showed the greatest number of IM Speeds received, which may have been a result of them continuing to lose spacing due to non-compliance. These two flights also showed low overall conformance with regard to both SEL and actual speed during this phase.

UPS857 on Night 3 showed low compliance, likely due to the crew noting "numerous commands to M_{MO}" in their questionnaire. Consistent with the compliance results, Figure 4-48 shows that UPS857 demonstrated low overall conformance during the Initial Descent Phase. From the actual speed results in Section 4.2.12, it did not appear that the crew was attempting to conform through other methods of speed control.

Per Section 4.2.13, it is unclear why UPS903 Night 3, did not comply with the IM Speed exactly. Despite this, UPS903 SEL conformance within +/- 5 kts during this phase is still over 90%.

Overall conformance is consistent with compliance. The eight flights that showed high compliance in following the IM Speeds were within +/- 5 kts of the IM Speed for at least 80% of the phase.

4.4.4 Maintain: BRRWN Restriction

As shown in Figure 4-2, the BRRWN Restriction Phase is defined as the period of time between Initial Descent as defined above and the BRRWN fix. It includes the deceleration to meet the BRRWN SCR, which was typically a speed reduction from 320+ kts down to approximately 240 kts at 11,000 ft at BRRWN. Aircraft were still in a clean configuration at this point.

Figure 4-49 shows the number of IM Speeds each flight received in the BRRWN Restriction Phase and how crews complied.

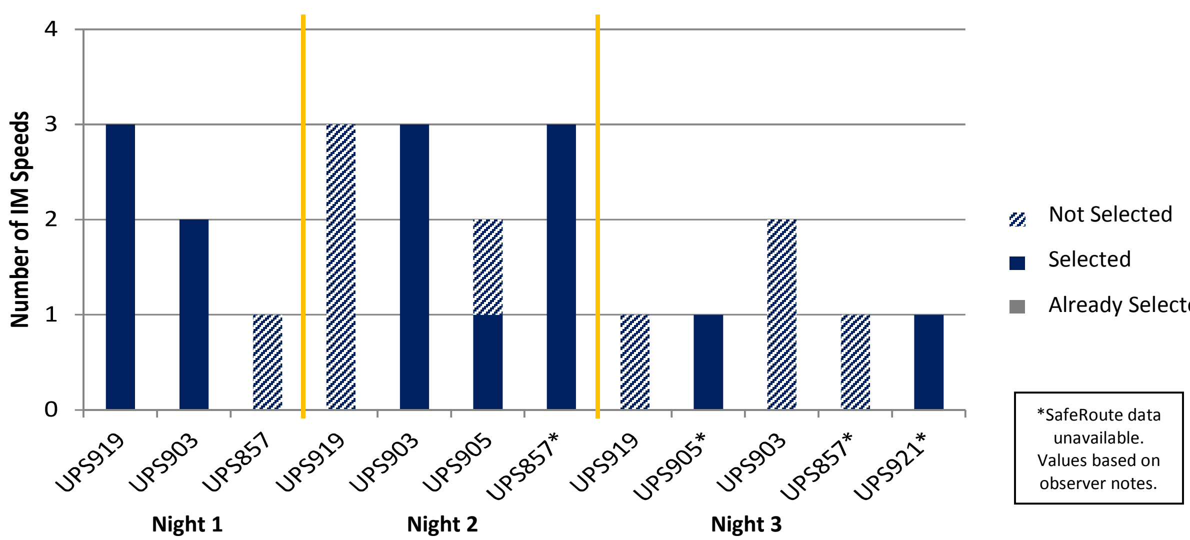


Figure 4-49. IM Speed Compliance (SEL) – BRRWN Restriction

Figure 4-50 shows the percentage of time the selected speed value on the MCP was in conformance with the IM Speed during the BRRWN Restriction Phase.

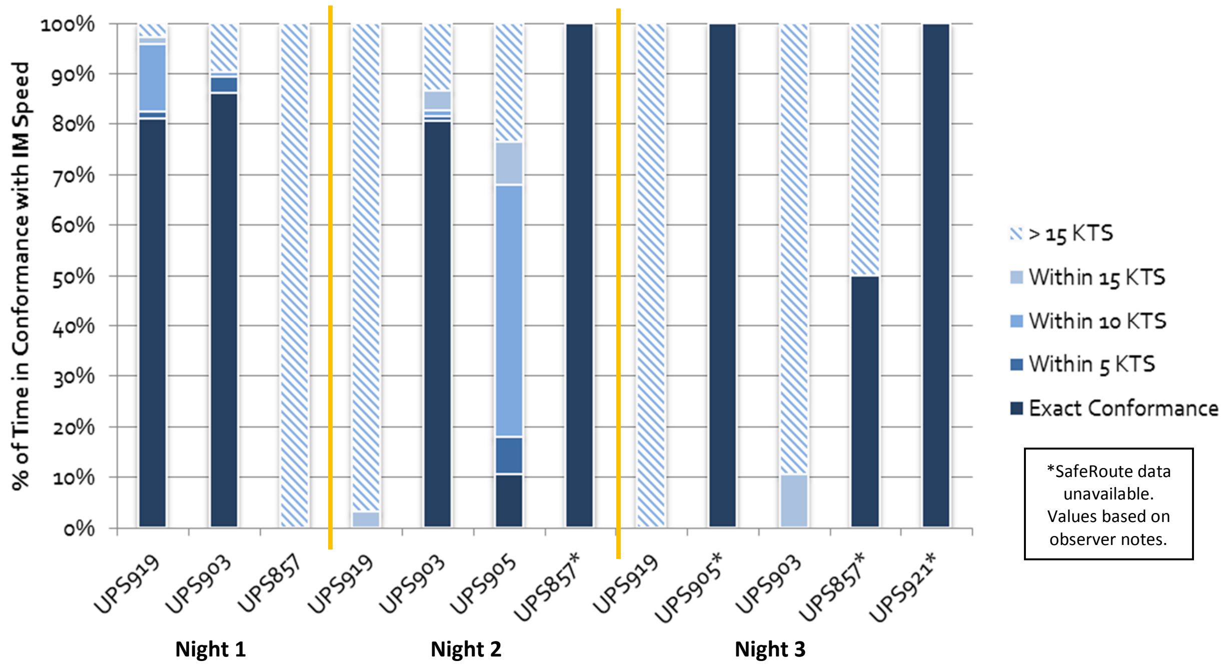


Figure 4-50. IM Speed Conformance (SEL) – BRRWN Restriction

Figure 4-49 and Figure 4-50 show that of the 12 flights, 6 had high IM Speed compliance and conformance with respect to SEL through the BRRWN Restriction Phase. However, as shown in Figure 4-51, UPS857 Night 1, UPS919 Night 2, and UPS903 Night 3 showed higher conformance in this phase with respect to actual aircraft speed. Although UPS857 Night 3 did not show higher conformance per the figure, Figure 4-33 suggests that the crew still intended to match the lead's deceleration at BRRWN with respect to actual speed. It is possible that these crews may have attempted to conform to the IM Speed through means other than SEL. However, overall conformance with respect to actual speed is lower during this phase as aircraft deceleration often lagged speed change inputs. As such, good conformance with respect to actual speed does not necessarily mean that the actual speed instantaneously matches the IM Speed following a large IM Speed change.

Overall conformance is consistent with compliance. The six flights that showed high compliance in following the IM Speeds were within +/- 5 kts of the IM Speed for at least 80% of the phase.

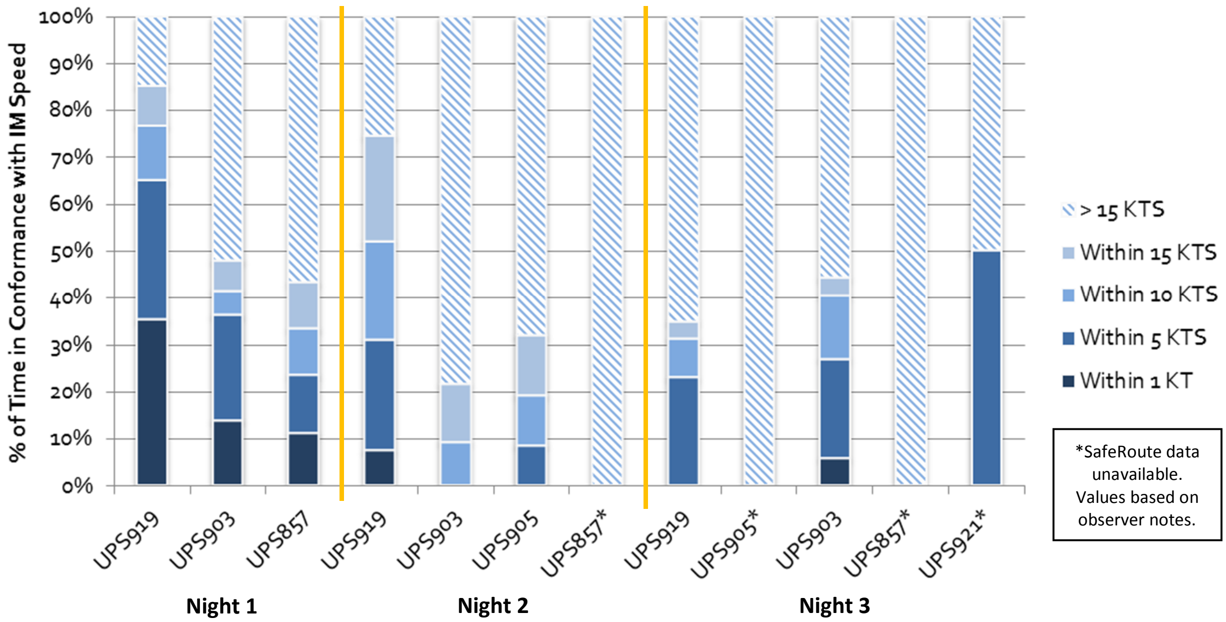


Figure 4-51. IM Speed Conformance (Actual) – BRRWN Restriction

Crew behavior at BRRWN for each flight is summarized in Table 4-13.

Table 4-13. Speed Reduction Behavior to BRRWN

Night	IM-S AA Flight	Crew Behavior Before BRRWN	Actual Speed at BRRWN (KIAS) [SCR = 240 kts]	Spacing at BRRWN (sec) [ASG = 145 sec]
1	UPS857	Crew → 240 first; IM Speed then reduced	267	150
	UPS903	IM Speed reduced; Crew selected IM Speed	266	146
	UPS919	IM Speed reduced; Crew selected IM Speed	239	147
2	UPS857*	IM Speed reduced; Crew selected IM Speed	253	Unknown
	UPS905	Crew → 240 first; IM Speed then reduced	258	149
	UPS903	IM Speed reduced; Crew selected IM Speed	255	142
	UPS919	IM Speed reduced; Crew responded → 240	259	158
3	UPS921*	IM Speed reduced; Crew selected IM Speed	247	Unknown
	UPS857*	IM Speed reduced; Crew responded → 240	307	Unknown
	UPS903	Crew → 240 first; IM Speed then reduced	254	149
	UPS905*	IM Speed reduced; Crew selected IM Speed	313	Unknown
	UPS919	Crew → 240 first; IM Speed then reduced	251	173

*SafeRoute data unavailable. Results based on observer notes.

As shown in the table, only one crew appeared to cross BRRWN with an actual speed less than 240 kts. Six crews appeared to exactly comply with each of their IM Speeds during this phase. Four crews initiated the speed reduction before the IM Speed value started to decrease. It is unknown whether they were aware that the FIM equipment was constrained to limit IM Speeds to 250 kts below 11,000 ft. As the aircraft approached 11,000 ft and the IM Speeds approached 250 kts to match the Target Aircraft deceleration, crews maintained 240 kts SEL. Not Selected IM Speeds in these cases primarily resulted from crews ignoring the IM Speed step-down values (e.g. 280, 265, 250, etc.). One exception occurred with UPS905, Night 2. In this case, the crew reduced to 240 kts before the IM Speed reduced. However, as the IM Speed stepped down from 260 kts to 250 kts, the crew increased SEL to match it at 250. Shortly thereafter, however, the crew reduced SEL again to 240 kts, independent of the IM Speed. Despite reducing "early", these four flights still crossed BRRWN with actual aircraft speeds greater than 240 knots.

Two instances were observed where crews waited for the first slow-down IM Speed before reducing SEL, but then selected 240 kts instead of following the step-down IM Speeds. These aircraft crossed BRWWN with speeds well above 240 kts.

Spacing at BRRWN was within 5 seconds for all flights except UPS919 on Nights 2 and 3. Despite decreasing SEL to 240 kts before the IM Speeds decreased; these flights still crossed BRRWN at more than 10 kts above the speed restriction.

4.4.5 Maintain: Arrival Turn

As shown in Figure 4-2, the Arrival Turn Phase started as the aircraft crossed BRRWN and ended just before BRNBX. The phase was bounded by the 240 kt, 11,000 ft crossing restriction at BRRWN and the 230 kt, 4500 ft crossing restriction at BRNBX. This phase included a nearly 90 deg right turn at JMCSY, with no restrictions at the fix. From the BRRWN One procedure, crews were instructed to set initial flaps no later than BRNBX. Figure 4-52 shows the number of IM Speeds each flight received in the Arrival Turn Phase and how crews complied.

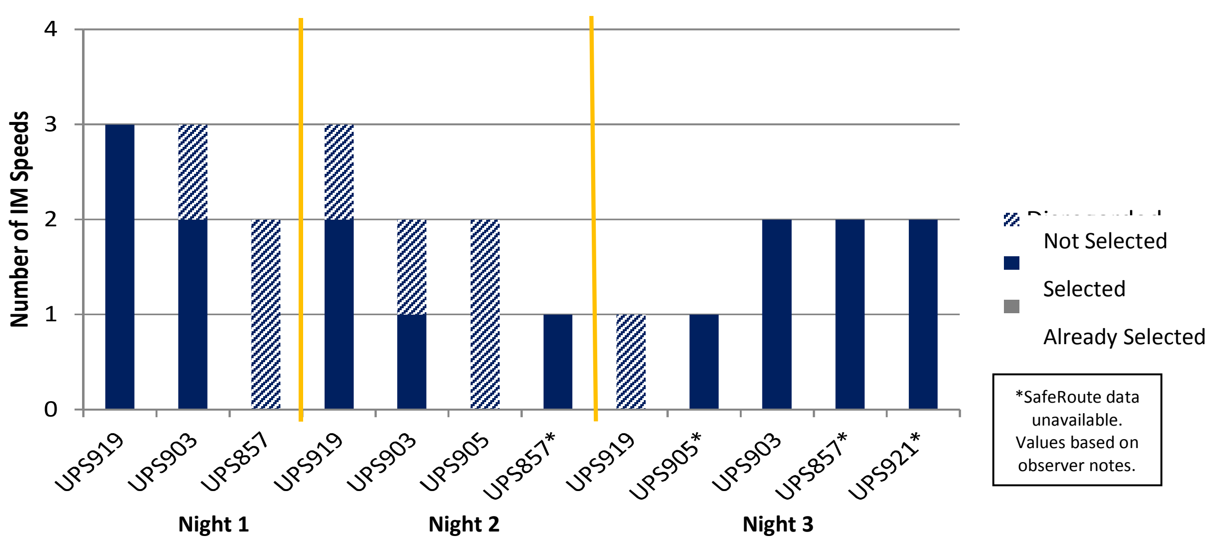


Figure 4-52. IM Speed Compliance (SEL) – Arrival Turn

Figure 4-53 shows the percentage of time SEL was in conformance with the IM Speed during the Arrival Turn Phase.

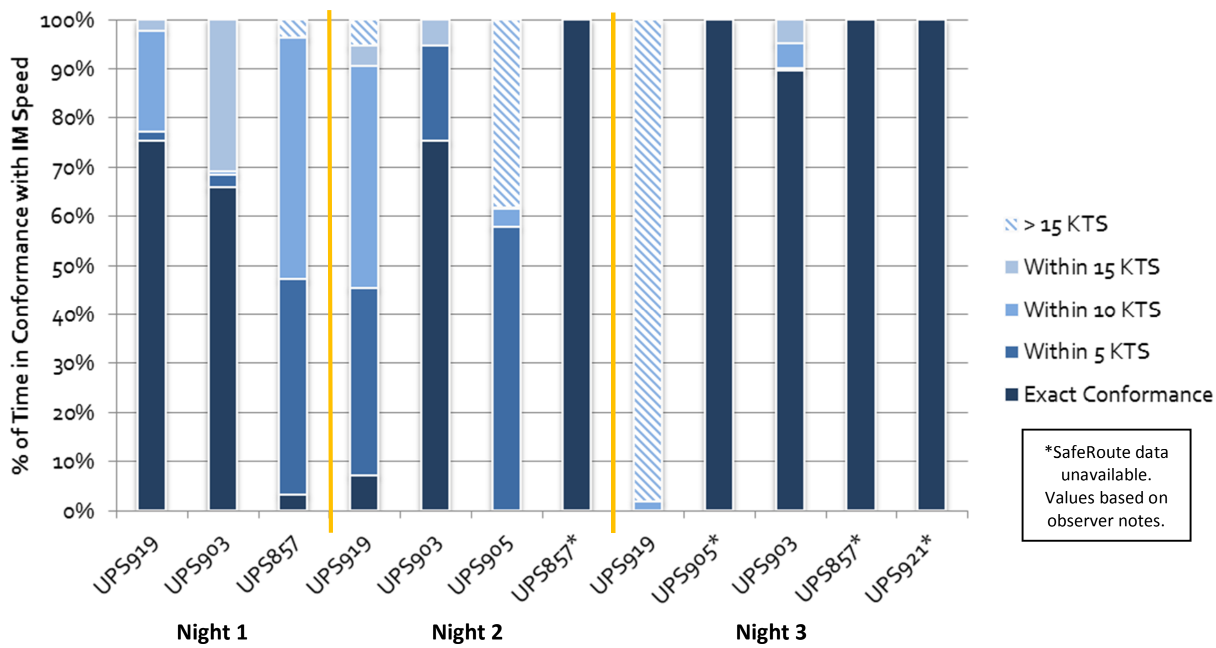


Figure 4-53. IM Speed Conformance (SEL) – Arrival Turn

Half the flights selected all of the IM Speeds during this phase and showed high corresponding conformance. Six flights did not select IM Speeds in the Arrival Turn Phase, as shown in Figure 4-52; however, five of these showed medium conformance despite not complying with one or more IM Speeds. Only UPS919 Night 3 showed both low compliance and low conformance during this phase.

4.4.6 Maintain: Final Descent

As shown in Figure 4-2, the Final Descent Phase started as the aircraft crossed BRNBX and ended when the Target Aircraft touched down (TGT TD). The phase was bounded by the 230 kt, 4500 ft crossing restriction at BRNBX and included a slight left turn and 190 kt, 3000 ft restriction at UPSCO. From the BRRWN One procedure, crews were instructed to set next flaps no later than UPSCO. The phase also included the 170 kt or less, 2400 ft restriction at the FAF (PARCL) for some flights, but in some cases the Target Aircraft touched down before the IM Aircraft reached this fix.

Several crews were still above 1500 ft. AGL when the Target Aircraft touched down. As a result, they continued to receive IM Speeds after this period. These IM Speeds were not counted in the following analyses but can be reviewed in Appendix D. Figure 4-54 shows the number of IM Speeds each flight received in the Final Descent Phase and whether crews exactly complied.

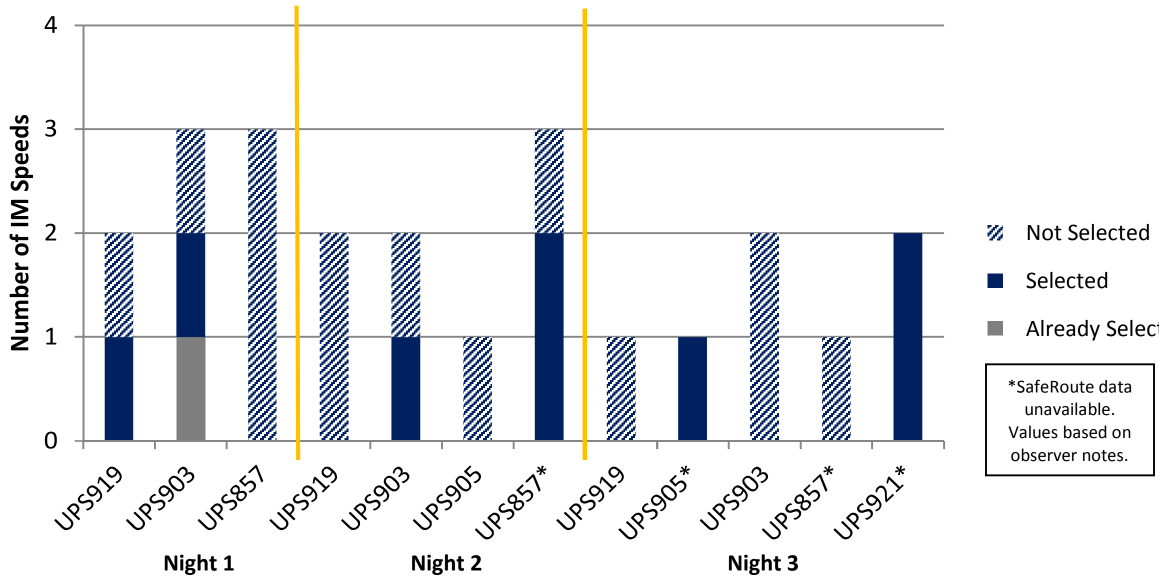


Figure 4-54. IM Speed Compliance (SEL) – Final Descent

Figure 4-55 shows the percentage of time the Selected Speed value on the MCP was in conformance with the IM Speed during the Final Descent Phase.

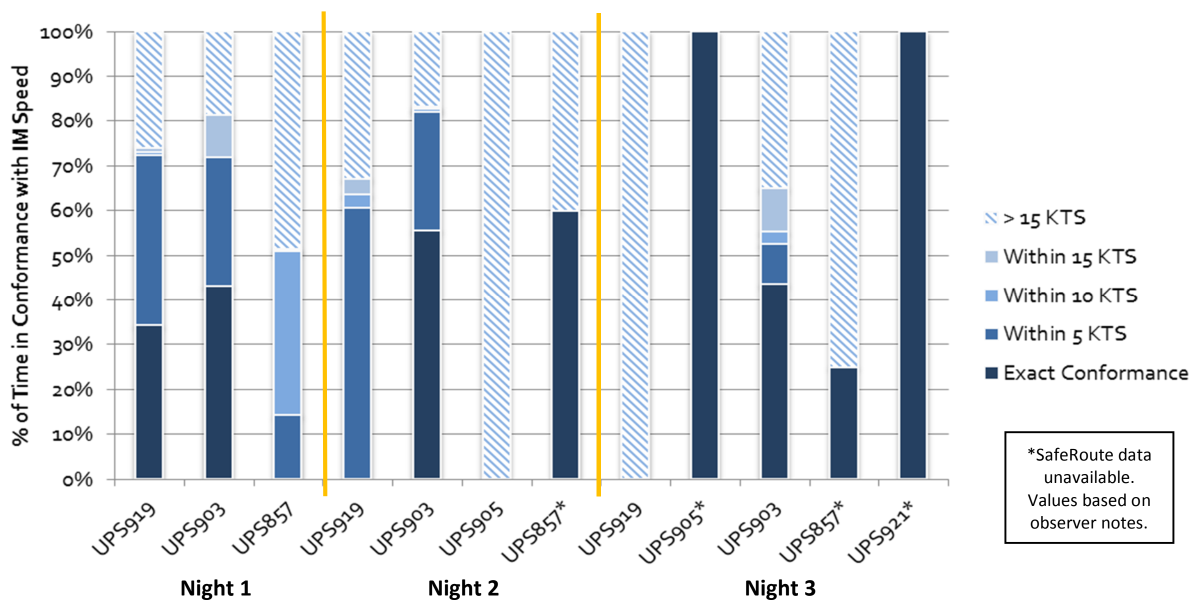


Figure 4-55. IM Speed Conformance (SEL) – Final Descent

As shown in Figure 4-54 and Figure 4-55, conformance during the Final Descent Phase generally is consistent with compliance. Two flights showed total compliance and conformance, though this could be due to the coarseness of observer notes. With regard to SEL, overall compliance and conformance during this phase were notably lower than in previous phases. However, three flights that showed relatively high SEL compliance, UPS857 Night 2, UPS921 Night 3, and UPS905 Night 3, all relied on observer notes for data. As such, compliance may appear higher than it was as it would have been easy for observers to miss crew SEL deviations during this dynamic period of flight.

One possible reason for the relatively low compliance and conformance are the arrival fix SCRs as well as final decelerations for configuring to land. The IM operational concept suggests that IM-S AA crews should not be bound by arrival fix speed restrictions. This is consistent with language on the procedure (Figure 3-1) which states that IM-S AA aircraft are exempt from having to maintain +/- 10 KIAS with the published speeds. For this test, however, crews were instructed by the IM training material to "Fly no faster than published [OPD] speeds to ensure a stabilized approach even if AGD commands a faster speed." These inconsistent instructions may have created confusion for crews. As such, an analysis was performed to determine how often the IM Speeds were in conflict with the SCR speeds and how crews responded via SEL. Of particular interest was whether crews did not select IM Speeds in order to comply with an SCR.

A summary of IM, SEL, and Actual Aircraft Speeds at the Final Descent SCR's is provided in Table 4-14. For reference, the BRNBX SCR is 230 kts, the UPSCO SCR is 190 kts, and the PARCL SCR is 170 kts or less. In a few cases, flights crossed PARCL after their Target aircraft touched down. These instances are shown with lighter text and an (~) by the IM Speed value at PARCL.

Table 4-14. IM, SEL, and Actual Aircraft Speeds at Arrival Fix Crossing Restrictions

Night	IM-S AA Flight	BRNBX (SCR = 230 kts)			UPSCO (SCR = 190 kts)			PARCL (SCR ≤ 170 kts)		
		IM Speed (kts)	SEL Speed (kts)	Actual Speed (kts)	IM Speed (kts)	SEL Speed (kts)	Actual Speed (kts)	IM Speed (kts)	SEL Speed (kts)	Actual Speed (kts)
1	UPS857	235	230	231	200	210	210	169	153	168
	UPS903	235	220	222	171	220	220	170~	155	*196*
	UPS919	205	205	226	175	176	201	172~	156	*155*
2	UPS857*	225	225	243	169	169	238	168~	139	*198*
	UPS905	250	192	211	195	174	176	167~	138	*144*
	UPS903	205	205	206	174	174	176	173	170	171
	UPS919	215	195	211	172	175	178	170~	155	*164*
3	UPS921*	230	230	238	230	230	230	162	162	150
	UPS857*	235	235	Unk	235	194	Unk	168	138	Unk
	UPS903	240	240	250	175	240	238	172	160	192
	UPS905*	250	250	238	250	250	229	175	175	206
	UPS919	250	210	228	230	210	213	200~	176	*199*

*SafeRoute data unavailable. Results based on observer notes.
~Flight crossed PARCL after TGT TD.

An analysis was performed to examine whether the SCRs were contributing factors for crews not selecting IM Speeds.

Table 4-15,

Table 4-16, and Table 4-17 summarize for each night how the IM Speeds and actual aircraft speeds related to the SCR speeds at each fix, the crew SEL action at the time of the fix crossing, and whether the crew did not select an IM Speed in order to comply with the SCR. This was defined as either of the following situations:

1) Cases in which the crews selected the SCR value exactly over a differing IM Speed value.
2) BRNBX or UPSCO: Cases where the IM Speed presented a value *greater or less than* 10 kts of the SCR values *and* the crew either selected a speed or crossed the fix with an actual speed that was within +/- 10 kts of the SCR.
3) PARCL: Cases where the IM Speed presented a value *greater than* 10 kts of the SCR value *and* the crew either selected a speed or crossed the fix with an actual speed that was + 10 kts or less of the SCR value.

Instances where the IM Speed was outside of the SCR tolerance are shown in bold in the *IM Speed – SCR Speed* column. Flights that crossed PARCL after their Target touched down are shown with lighter text and an (~) by the PARCL row label. The final column summarizes whether crews did not select the IM Speed to meet the SCR.

Table 4-15. Summary of Crew SEL Actions over Fix Speed Restrictions – Night 1

Night	Flight	Fix	IM Speed – SCR Speed	Actual Speed – SCR Speed	Crew SEL Action	Not select IM Speed to comply with the SCR?
1	UPS857	BRNBX	+5 kts	+1 kt	SEL was set to SCR.	Yes
		UPSCO	+10 kts	+20 kts	SEL was 20 kts faster than the SCR.	No
		PARCL	-1 kt	-2 kts	SEL was 17 kts slower but in compliance with the SCR.	No
	UPS903	BRNBX	+5 kts	-8 kts	SEL was 10 kts slower than the SCR.	No
		UPSCO	**-19 kts**	+30 kts	SEL was 30 kts faster than the SCR.	No
		PARCL~	0 kts	+26 kts	Crew selected the IM Speed, but reduced speed just before crossing (outside of IM-S AA period).	No
	UPS919	BRNBX	**-25 kts**	-4 kts	SEL was set to IM Speed value.	No
		UPSCO	**-15 kts**	+11 kts	SEL was set to IM Speed value, but the crew increased speed by 1 kt before crossing the fix.	No
		PARCL~	+2 kts	-15 kts	SEL was 14 kts slower but in compliance with the SCR.	No

*SafeRoute data unavailable. Results based on observer notes.
~Flight crossed PARCL after TGT TD.

Table 4-16. Summary of Crew SEL Actions over Fix Speed Restrictions – Night 2

Night	Flight	Fix	IM Speed – SCR Speed	Actual Speed – SCR Speed	Crew SEL Action	Not select IM Speed to comply with the SCR?
2	UPS857*	**BRNBX**	-5 kts	+13 kts	SEL was set to IM Speed value.	No
		UPSCO	**-21 kts**	+48 kts	SEL was set to IM Speed value.	No
		PARCL~	-2 kts	+28 kts	SEL was 31 kts slower but in compliance with the SCR.	No
	UPS905	**BRNBX**	**+20 kts**	-19 kts	SEL was 38 kts slower than the SCR.	No
		UPSCO	+5 kts	-14 kts	SEL was 16 kts slower than the SCR.	No
		PARCL~	-3 kts	-26 kts	SEL was 38 kts slower but in compliance with the SCR.	No
	UPS903	**BRNBX**	**-25 kts**	-24 kts	SEL was set to IM Speed value.	No
		UPSCO	**-16 kts**	-14 kts	SEL was set to IM Speed value.	No
		PARCL	+3 kts	+1 kt	SEL was set to 170 kts (highest SCR value).	Yes
	UPS919	**BRNBX**	**-15 kts**	-19 kts	SEL was 35 kts slower than the SCR.	No
		UPSCO	**-18 kts**	-12 kts	SEL was 15 kts slower than the SCR.	No
		PARCL~	0 kts	-6 kts	SEL was 15 kts slower but in compliance with the SCR.	No

*SafeRoute data unavailable. Results based on observer notes.
~Flight crossed PARCL after TGT TD.

Table 4-17. Summary of Crew SEL Actions over Fix Speed Restrictions – Night 3

Night	Flight	Fix	IM Speed – SCR Speed	Actual Speed – SCR Speed	Crew SEL Action	Not select IM Speed to comply with the SCR?
3	UPS921*	BRNBX	0 kts	+8 kts	SEL was set to IM Speed value.	No
		UPSCO	**+40 kts**	+40 kts	SEL was set to IM Speed value.	No
		PARCL	-8 kts	-20 kts	SEL was set to IM Speed value.	No
	UPS857*	BRNBX	+5 kts	UNK	SEL was set to IM Speed value.	No
		UPSCO	**+45 kts**	UNK	SEL was 4 kts faster than the SCR.	Yes
		PARCL	-2 kts	UNK	SEL was 32 kts slower but in compliance with the SCR.	No
	UPS903	BRNBX	+10 kts	+20 kts	SEL was set to IM Speed value.	No
		UPSCO	**-15 kts**	+48 kts	SEL was 50 kts faster than the SCR.	No
		PARCL	+2 kts	+22 kts	SEL was 10 kts slower but in compliance with the SCR.	No
	UPS905*	BRNBX	**+20 kts**	+8 kts	SEL was set to IM Speed value.	No
		UPSCO	**+60 kts**	+39 kts	SEL was set to IM Speed value.	No
		PARCL	+5 kts	+36 kts	SEL was set to IM Speed value.	No
	UPS919	BRNBX	**+20 kts**	-2 kts	SEL was 20 kts slower than the SCR.	Yes
		UPSCO	**+40 kts**	+23 kts	SEL was 20 kts faster than the SCR.	No
		PARCL~	**+30 kts**	+29 kts	SEL was 6 kts faster than the highest SCR value.	Yes

*SafeRoute data unavailable. Results based on observer notes.
~Flight crossed PARCL after TGT TD.

Across all of the flights, there were 16 out of 30 possible (where PARCL was within the IM-S AA period) instances where the IM Speed was outside of the published SCR tolerances (by more than +/- 10 kts). In half of these cases, crews still selected the IM Speed exactly (or within 1 kt). Of the remaining eight instances, four crews selected speeds faster than the SCR values and four crews selected speeds slower than the SCR values.

Furthermore, across all of the flights, there were only four observed instances (with PARCL in the IM-S AA period) where crews appeared to not select an IM Speed in order to comply with an SCR. These were:

- Two cases (UPS857 Night 1 at BRNBX and UPS903 Night 2 at PARCL) in which crews selected the SCR value exactly over a differing IM Speed value (though for each the IM Speed was within tolerance of the SCR).
- One case (UPS857 Night 3 at UPSCO) where the IM Speed was more than 10 kts greater than the SCR but the SEL was within the SCR tolerance.
- One case (UPS919 Night 3 at BRNBX) where even though both the IM Speed and SEL exceeded the SCR tolerance, the actual aircraft speed over the fix was within the SCR tolerance.

Overall these results suggest that the SCRs were *not* a significant contributing factor for crews not selecting IM Speeds in the Final Descent Phase of the arrival. Instead, lower IM Speed conformance was more likely due to crew variability in stabilizing the aircraft in preparation for landing.

The data was further examined to determine if the IM Speeds contributed to aircraft crossing the fixes with crossing restrictions outside of the published tolerances. A review of IM and (known[17]) actual aircraft airspeeds over the OPD fixes in Table 4-14 shows that:

- At BRNBX, 5 of the 11 IM-S AA aircraft crossed with (known) actual airspeeds outside of the published tolerance. Three flights were slower and two were faster. For two of the slower flights, the IM Speeds were also slower than the SCR tolerance. For the other slower flight, the IM Speed was above the published tolerance. For the two flights that crossed BRNBX faster than the published SCR tolerance, the IM Speeds were within the limits (230 +/- 10 kts).
- At UPSCO, all 11 IM-S AA aircraft crossed with (known) actual airspeeds outside of the published tolerance. Three flights were slower and eight were faster. For two of the slower flights, the IM Speeds were also slower than the SCR tolerance. For the other slower flight, the IM Speed was within the published tolerance. Four of the eight flights that crossed BRNBX faster than the published SCR tolerance, exhibited IM Speeds that also exceeded the limits.
- At PARCL, 5 of the 11 IM-S AA aircraft crossed with (known) actual airspeeds in excess of the SCR + 10 kts. In only one of these cases (UPS919 Night 3), however, was the IM Speed also in excess of the SCR value + 10 kts. However, the crew of this aircraft had elected not to continue following the IM Speeds at this point, as described in Section 4.2.15.

In summary, there were 21 out of 33 instances in which IM Aircraft actual speeds were outside of the published SCR tolerances. In six of these instances the IM Aircraft crossed slower than the tolerance. Four of these may have been related to IM Speeds also lower than the published tolerance. Four of the 15 cases where the IM Aircraft crossed in excess of the published SCR tolerances exhibited IM Speeds that also exceeded the SCR tolerance. As such it appears that

[17] UPS857 on Night 3 was not included in these counts as SafeRoute data was unavailable for this flight and the observer did not record actual aircraft speed over the fixes.

higher actual speeds across the fixes was not *primarily* due to the IM procedure. Overall, IM Speeds may have contributed to 8 out of 21 cases of aircraft crossing the fixes outside of the published SCR tolerances.

4.4.7 Flight Crew-Initiated Speed Changes

Conformance deviations resulted from crews selecting speeds that were different from the IM Speed at the time. These could have either been in response to an IM Speed (with a value that did not match the IM Speed), or they could have been speed changes between IM Speeds. Based on the timelines of Appendix D, the reasons for each of the flight crew-initiated speed changes were categorized to the extent possible. Table 4-18 summarizes the likely reasons and the frequencies of the flight crew-initiated speed changes.

Table 4-18. Counts and Reasons for Flight Crew-Initiated Speed Changes

Reason	Total	UPS919	UPS903	UPS857	UPS919	UPS903	UPS905	UPS857*	UPS919	UPS905*	UPS903	UPS857*	UPS921*
1. Target aircraft announces speed change; crew does not wait for IM Speed	1			1									
2. Crew appears to attempt to manage interval on their own	15		3				7	1	3		1		
3. Crew reduces to BRRWN SCR (240 kts) independent of IM Speed reduction	8	1		1	1		2		1		1	1	
4. IM Speed is outside the SCR tolerance and crew sets SEL to comply with SCR	2								1			1	
5. Crew performs final speed reductions to FAS independent of IM Speeds	14	1		4	2	1	2	1			2	1	
6. Crew adjusts SEL to select with IM Speed after being out of conformance	12	2					8				1		1
7. Crew appears to select IM Speed, but selects slightly different SEL value for unknown reasons	6	1	1		1	2					1		
Unable to determine specific reason	34	*4*		*2*			*17*		*2*			*8*	*3*
Total Crew-Initiated Changes	**94**	9	4	8	4	3	36	2	7	0	6	11	4

*SafeRoute data unavailable. Results based on observer notes.

The results show that flight crews initiated speed changes independently of the IM Speed for several reasons. Three main reasons, however, accounted for nearly half of the occurrences. The first was when crews appeared to attempt to manage their spacing interval with the Target Aircraft on their own. This was seen most frequently with UPS905, but was observed with several other crews as well. This likely resulted from ambiguity about the official start of the IM-S AA operation. Crews were instructed to maintain a 22 NM interval and then transition to IM-S AA. However, the exact transition point may not have been clear across crews as several continued to initiate their own speeds to manage to the distance inside of the 300 NM. After TOD, there were fewer cases of this occurring, suggested that crews were less sure what the distance needed to be with their Target Aircraft and were more inclined to follow the IM Speeds. Individual cases can be reviewed in Appendix D.

The second most common reason was when crews performed final speed reductions to FAS independent of the IM Speeds, which is an expected and acceptable behavior for the purpose of the test. This occurred across nearly all of the flights and was primarily comprised of cases where the crew reduced speeds below 200 kts and stepped down to the aircraft FAS. In most cases the reductions in IM Speed below 200 kts occurred either before crews were ready to begin their final deceleration to FAS, or after crews had already started reducing. Only in a few cases did the crews reduce speed below 200 kts on the same schedule as the IM Speed reductions. This could be related to the flap extension schedule, but data on aircraft configuration timing is not available. The latitude to which flight crews should ultimately be permitted to deviate from IM Speeds in the final phase of flight, and impact on performance, remains to be determined.

As examined in Section 4.4.6, most flight crew-initiated speed reductions to FAS do not appear to be related to conflicts between the IM Speed and the SCRs at BRNBX, UPSCO, and PARCL. There were, however, several occurrences where crews selected 240 kts to comply with the SCR at BRRWN independently of the IM Speed. These cases are discussed in detail in Section 4.4.4.

The third most common reason was due to crews adjusting SEL to conform to the IM Speed after being out of conformance. However, the majority of these occurred with UPS905 on Night 2, which was responsible for more than a third of the total number of crew-initiated speed changes. As shown in Section 4.2.7, this crew mostly selected the IM Speeds, but also independently made numerous SEL changes. The reason for half of the changes cannot be determined from the data or observer notes, although at one point the observer noted that the crew appeared to be flying relative to the “picnic table” feature of the CDTI. This may account for the high frequency of changes and suggests that this crew may not have been as familiar as other crews with the IM-S AA procedures. The rest of the changes appeared to be for similar reasons as other crews.

4.5 IM Speed Change Magnitudes

Another factor that has an impact on the experience of crew acceptance of IM Speeds is magnitude. Two types of IM Speed change magnitudes were evaluated: Incremental (INCR) and SEL. INCR change magnitude is simply the difference between a current and previous IM Speed. However, since crews were not always in compliance with the IM Speed, further analysis was performed to examine the degree to which the crew would need to adjust the SEL in order to comply with the IM Speed. The resulting metric is termed SEL change magnitude, and was thus calculated by subtracting aircraft SEL at the time of the change from the new IM Speed value. In both cases, a positive change magnitude indicates a speed-up and a negative change magnitude indicates a slow-down. When SafeRoute data was not available, the magnitude change values were based on observer notes of the IM Speed and SEL speed inputs. Since Mach IM Speed changes were rare, only the KIAS IM Speeds are included in the analyses.

4.5.1 Frequency Distributions

The frequency of IM Speed INCR and SEL change magnitudes was counted across all flights (except UPS905 on Night 1). The counts include all of the Selected, Already Selected, and Not Selected IM Speeds. Magnitude changes in this case are absolute values and include both speed-up and slow-down IM Speeds. Results are provided in Figure 4-56.

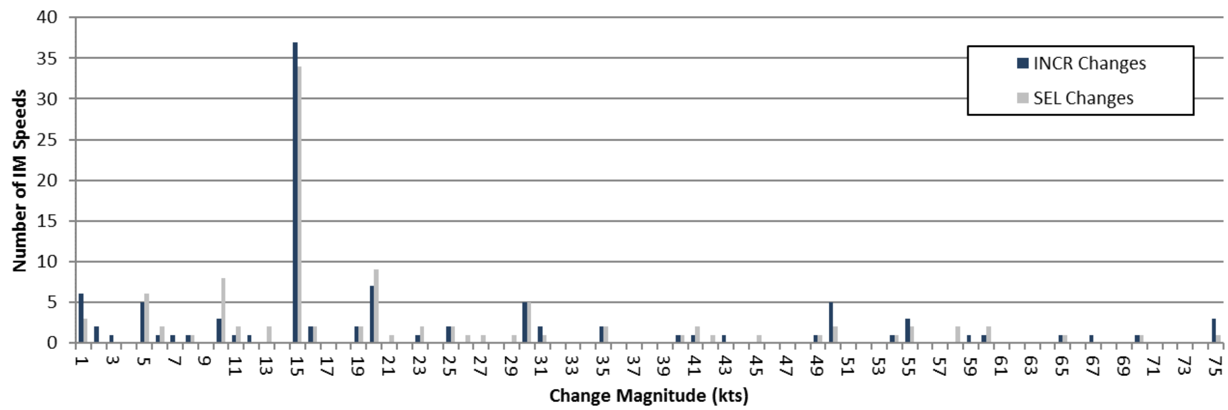


Figure 4-56. IM Speed INCR and SEL Change Magnitude Frequency Distribution

Of the 103 KIAS IM Speeds, the results show that 15 kt increments were by far the most common for both magnitude cases. IM Speeds were also observed in other increments as well, with 1, 5, 10, 20, 30, and 50 kts also frequently occurring values.

4.5.2 IM Speed SEL Change Magnitude Distribution by Flight

Figure 4-57 shows the number of IM Speeds for each flight that fall into each range of magnitude change values, relative to SEL. The figure shows the absolute value of the IM Speeds; i.e., it includes both speed-up and slow-down IM Speeds.

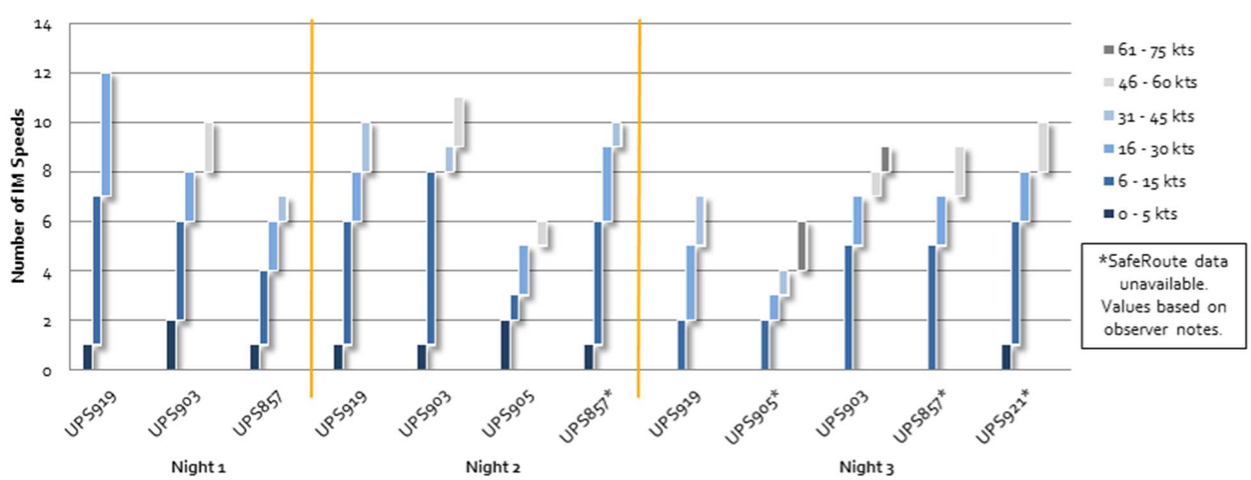


Figure 4-57. IM Speeds SEL Change Magnitude Distributions by Flight

Although 80% of the IM Speed SEL change magnitudes were 30 kts or less, some were much larger. These circumstances are discussed in the next section.

4.5.3 IM Speed Change Magnitudes by Arrival Phase

Further analysis was conducted to determine which phases of the arrival exhibited the largest IM Speed change magnitudes. Figure 4-58 summarizes where the majority of each magnitude change type that occurred by arrival phase, summed across all flights. The IM Speed counts[18] are counted in 15 kt changes, except for the 1 – 5 kt and 6 – 15 kt bins. Counts above the zero line indicate positive magnitude change (speedup) IM Speeds and counts below the line indicate negative magnitude change (slowdown) IM Speeds. The 2 Already Selected KIAS cases had a SEL magnitude change of zero and are not depicted in the figure.

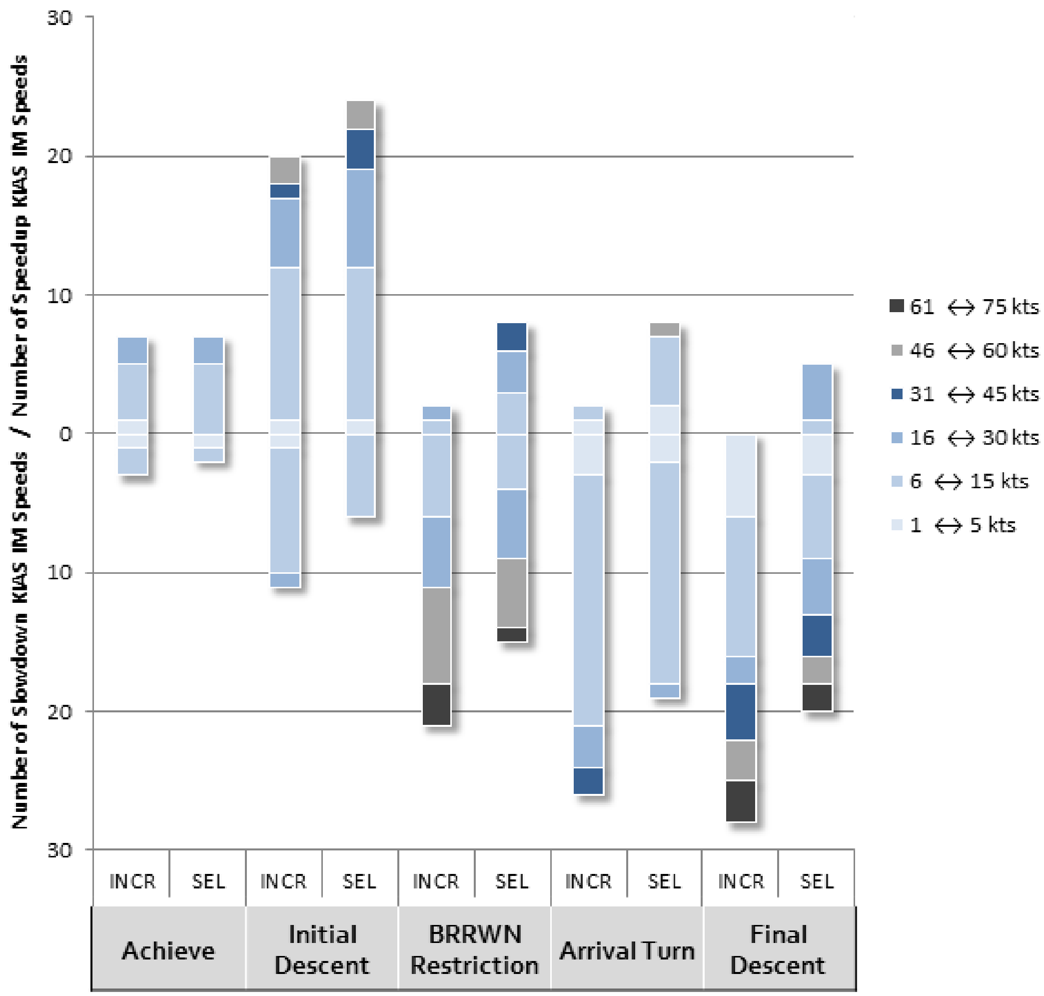


Figure 4-58. IM Speed Change Magnitudes by Phase

[18] Fewer KIAS IM Speeds were observed during the Achieve Phase since most aircraft were flying Mach during this period.

Conformance differences are primarily driven by crew-initiated speed changes. If each flight showed perfect compliance with the IM Speeds, there would be no difference between the two magnitude change types. Although generally small, some differences between the INCR and SEL change magnitude distributions were observed as shown in Figure 4-58. First, crew-initiated speed changes had the effect of increasing the number of positive SEL change magnitude IM Speeds. This is mostly due to crews reducing speed before reductions in the IM Speed, particularly during the BRRWN Restriction and Final Descent Phases. Since the IM Speed values stepped down in smaller increments, the INCR values were usually faster than current SEL when crews initiated their own speed reductions. This had the effect of the IM Speed suggesting that the aircraft increase speed.

The overall effect of the Initial Descent IM Speeds was to increase aircraft speed, likely to match the lead aircraft speed at the start of the descent. The majority of these changes were in increments of 30 kts or less. Some speed-up IM Speeds were observed in other phases, but the majority were slow-down IM Speeds.

The vast majority of IM Speeds had magnitude changes less than or equal to 30 kts. The IM Speeds with magnitude change differences greater than 30 kts were observed mainly during the BRRWN Reduction and Final Descent Phases. As noted in Section 1.3.4, the FIM algorithm contained logic that tried to avoid numerous, smaller IM Speed changes in favor of fewer, larger IM Speed changes. The observed speed change magnitudes appear to confirm this behavior.

4.6 IM Speed Trend Changes

Although IM-S FIM algorithms are being designed to provide useful and stable speeds to aircrew, some IM Speeds may not make intuitive sense to aircrew at times. This may especially be the case if the speed-up/slow down speed change trends change. If the aircrew does not understand why they are receiving certain IM Speeds, they may lose trust in the equipment and the operation. However, since the algorithm reacts to Target Aircraft behavior, these changes may be appropriate and necessary to maintain spacing.

In order to understand whether IM Speed trend changes may have been a factor in aircrew acceptance, the occurrences of each trend change were counted and analyzed. Figure 4-59 shows the number of times the IM Speed (Mach and KIAS) trend changed from *speed up to slow down* or from *slow down to speed up* per flight during the IM-S AA period. The trend changes are relative to the previous IM Speed value at the time of the change. The following examples demonstrate how the trend changes were counted:

- Example 1: If the aircraft began the IM-S AA period with an IM Speed or series of IM Speeds that suggested the crews increase SEL, but then received an IM Speed or *series* of IM Speeds that led the crews to decrease SEL, this is counted as *one* trend change.
- Example 2: If the effect of a set of IM Speeds was to suggest the crew increase SEL by 13 kts, then decrease SEL by 58 kts, then increase SEL again by 10 kts, this is counted as *two* trend changes.

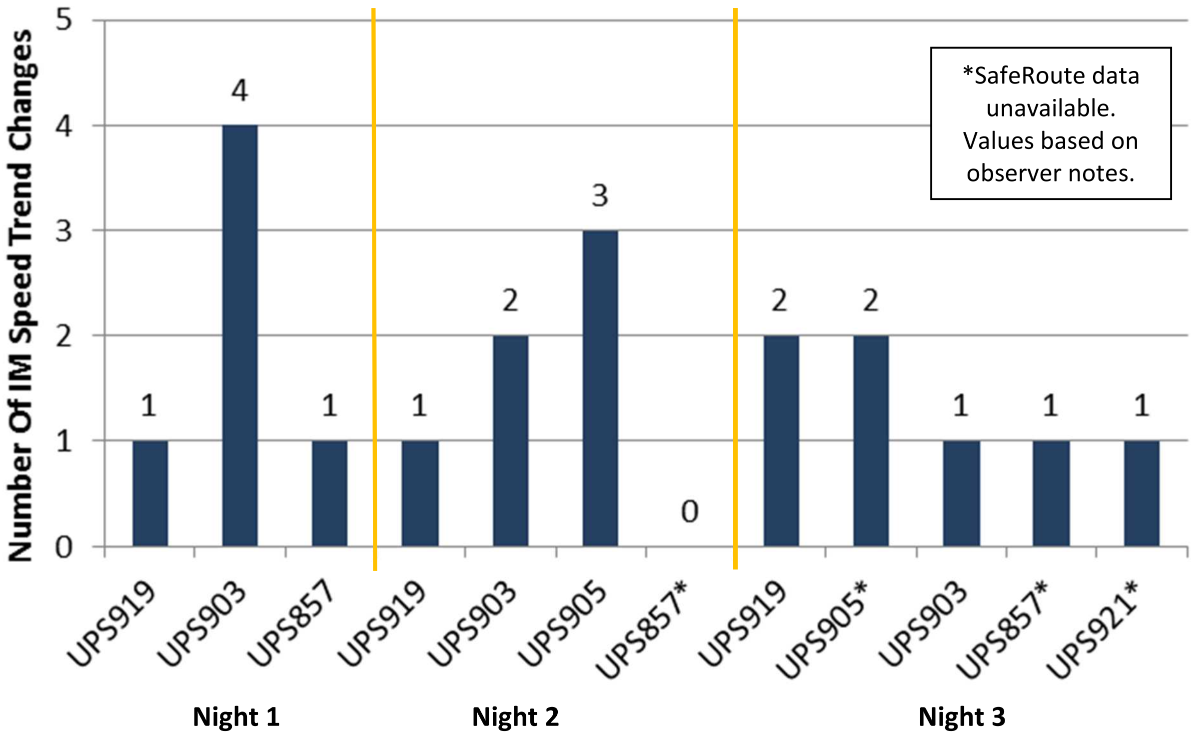


Figure 4-59. IM Speed Trend Changes

The results show that although every flight experienced at least one IM Speed trend change, overall they were relatively infrequent during the IM-S AA period. Per the narratives in Section 4.2, the reasons for the trend changes are summarized in Table 4-19.

Table 4-19. Reasons for IM Speed Trend Changes

Reason**	Total	Night 1			Night 2				Night 3				
		UPS919	UPS903	UPS857	UPS919	UPS903	UPS905	UPS857*	UPS919	UPS905*	UPS903	UPS857*	UPS921*
Trend change to reverse spacing opening / closing	3		1				1		1				
Change in IM Speed increase trend due to Target Aircraft speed reduction at BRRWN	11	1	1	1	1	1	1		1	1	1	1	1
Reason unclear	*5*		*2*			*1*	*1*			*1*			
Total	*19*	*1*	*4*	*1*	*1*	*2*	*3*	*0*	*2*	*2*	*1*	*1*	*1*

*SafeRoute data unavailable. Results based on observer notes.
** Reasons presumed, but likely.

The majority of the trend changes were a result of initially providing speed-up IM Speeds during the Achieve and/or Initial Descent Phases, then requiring the aircraft to slow in response to a decrease in the lead aircraft speed at BRRWN. Three trend changes clearly resulted from reversing the spacing performance opening or closing trends. The reasons for five of the trend changes could not be determined; i.e., the result of the trend did not appear to be consistent with increasing or decreasing spacing in a desired direction, or no spacing performance data was available.

4.7 IM Speed Response Times

The time crews took to respond to IM Speeds can be determined for the flights with SafeRoute data. Table 4-20 shows the average response time in seconds for the *Selected* IM Speeds in the Achieve Phase and the full Maintain Phase.

Table 4-20. IM Speed Average Crew Response Times

	Night 1						Night 2						Night 3			
	UPS919		UPS903		UPS857		UPS919		UPS903		UPS905		UPS919		UPS903	
Achieve																
Average Response Time (sec)	**5**		**6**		**305**		**9**		**9**		-		**21**		**7**	
n / SD	1	n/a	4	1.9	1	n/a	1	n/a	2	7.1	0	-	2	12.0	2	1.4
Maintain																
Average Response Time (sec)	**8**		**6**		**20**		**26**		**12**		**24**		**9**		**12**	
n / SD	12	2.6	8	2.5	3	14.6	3	21.9	9	12.5	3	21.8	4	3.5	2	5.7

For the IM Speeds that were selected (n = 57), all but one were responded to within 60 seconds. The average response time for all IM Speeds that were selected in 60 seconds or less (n = 56) was 11 seconds (SD = 10.5).

4.8 IM Speed Period and Acceptability

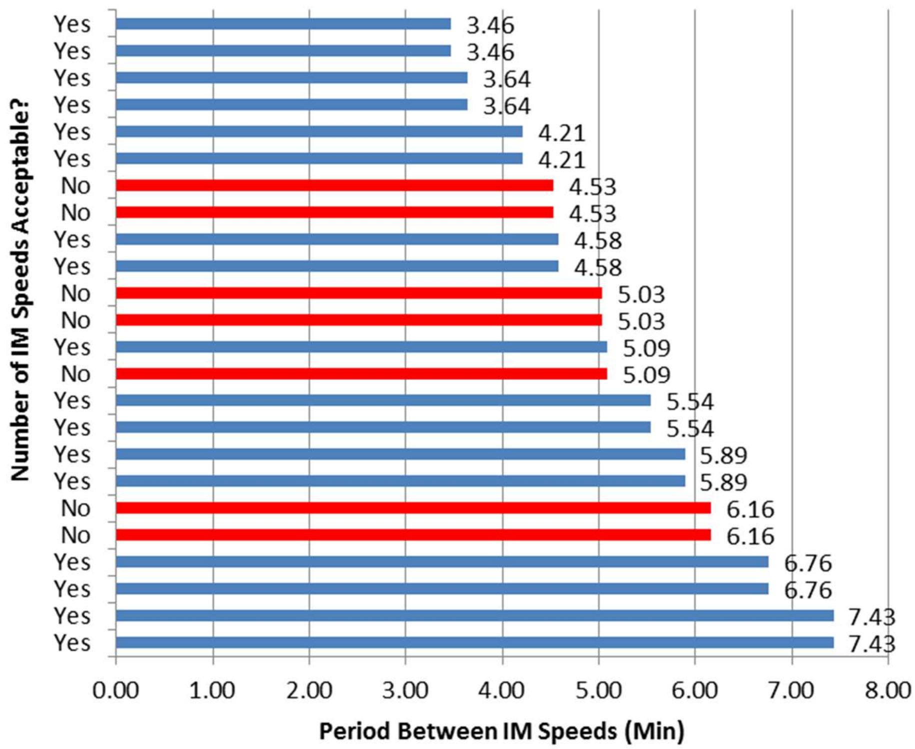
4.8.1 IM Speed Period

Table 4-21 shows how pilots, with their positions and roles noted as Captain (CPT) or First Officer (FO) and Pilot Flying (PF) or Pilot Monitoring (PM), responded when asked whether the number of IM Speeds they experienced during their flight was acceptable. It also provides the IM Speed average for the Total IM-S AA period as well as for the Achieve and Maintain Phases. This was calculated by dividing the number of minutes in each phase by the number of IM Speeds presented during those time periods. As with previous results, UPS905 from Night 1 (pilots "E" and "F") is not included as an equipment setup error prevented the display of IM Speeds to crews.

Table 4-21. Pilot Acceptance of Number of IM Speeds

Night	Flight	Pilot	Position	IM Speed **Total** (Average Min b/w Changes)	IM Speed **Achieve** (Average Min b/w Changes)	IM Speed **Maintain** (Average Min b/w Changes)	Number of IM Speeds Acceptable?
1	UPS857	A	CPT & PF	5.54	35.97	2.16	Yes
1	UPS857	B	FO & PM	5.54	35.97	2.16	Yes
1	UPS903	C	CPT & PF	3.46	7.24	1.75	Yes
1	UPS903	D	FO & PM	3.46	7.24	1.75	Yes
1	UPS919	G	CPT & PF	3.64	11.32	1.72	Yes
1	UPS919	H	FO & PM	3.64	11.32	1.72	Yes
2	UPS857	I	CPT & PF	4.58	9.50	2.13	Yes
2	UPS857	J	FO & PM	4.58	9.50	2.13	Yes
2	UPS905	K	CPT & PF	6.76	34.87	2.74	Yes
2	UPS905	L	FO & PM	6.76	34.87	2.74	Yes
2	UPS903	M	CPT & PF	4.21	17.27	1.83	Yes
2	UPS903	N	FO & PM	4.21	17.27	1.83	Yes
2	UPS919	H	CPT & PF	4.53	34.83	1.78	No
2	UPS919	O	FO & PM	4.53	34.83	1.78	No
3	UPS921	P	CPT & PF	5.09	12.33	2.38	No
3	UPS921	C	FO & PM	5.09	12.33	2.38	Yes
3	UPS857	Q	CPT & PF	5.89	18.00	2.43	Yes
3	UPS857	J	FO & PM	5.89	18.00	2.43	Yes
3	UPS903	M	CPT & PF	6.16	18.34	2.68	No
3	UPS903	N	FO & PM	6.16	18.34	2.68	No
3	UPS905	R	CPT & PF	7.43	36.00	2.67	Yes
3	UPS905	S	FO & PM	7.43	36.00	2.67	Yes
3	UPS919	H	CPT & PM	5.03	18.33	2.08	No
3	UPS919	O	FO & PF	5.03	18.33	2.08	No

The periods during the Achieve Phase are greater than that during Maintain since far fewer IM Speeds were presented over a much longer period. Across the flights, the IM Speed changed on a per flight basis on average between every seven and every 36 minutes during the Achieve Phase. In the Maintain Phase the IM Speed changed on a per flight basis on average between every 100 and every 180 seconds. Figure 4-60 graphically depicts each pilot's acceptance and IM Speed average results for the total IM-S AA period.



- The “No” ratings with a period of 4.53 came from UPS919 on Night 2.
- The “No” rating with a period of 5.03 came from UPS919 on Night 3.
- The “No” ratings with a period of 5.09 came from UPS921 on Night 3.
- The “No” rating with a period of 6.16 came from UPS903 on Night 3.

Figure 4-60. IM Speed Period and Pilot Acceptance

As shown in Figure 4-60, most crews felt the number of IM Speeds observed in the test was acceptable – with the highest being one IM Speed approximately less than every four minutes (less than every two minutes during the Maintain Phase). Normally IM Speed acceptability is assumed in the context of too many IM Speeds; e.g. a greater number of IM Speeds is considered less desirable than a fewer number. However, two pilots (Night 3 UPS921 CPT and Night 3 UPS903 FO) answered “no” and noted on their questionnaires that their number of IM Speeds was unacceptable as *not enough* were received, resulting in large change magnitude jumps. They would have preferred *more* IM Speeds to maintain a smoother speed profile. Per Figure 4-57, however, it did not appear that UPS921 on Night 3 received greater SEL magnitude changes than other crews. However, UPS903 on Night 3 was one of the only two flights to experience IM Speed magnitudes in the 61 – 75 kt range (relative to SEL). The other flight to experience IM Speed changes in this magnitude, UPS905 on Night 3, did not find the number of IM Speeds to be unacceptable.

The other “No” ratings (Night 2 and Night 3 UPS919 [same crews]) came from a crew that did not receive any more IM Speeds than most other crews. As such, they are more likely tied to the crew’s stated distrust of the system and their belief that the IM Speeds, as presented, were neither timely nor correct due to requested accelerations during descent (See Section 4.2.9 and Section 4.2.15 for discussion). Several other flights, such as UPS903 and UPS919 Night 1, UPS905 Night 3, etc., selected similar positive IM Speed SEL magnitudes during Initial Descent. As such, it is unclear whether Night 2 and Night 3 UPS919 had operational reasons for not selecting the IM Speeds.

4.8.2 IM Speed Acceptability Pilot Questionnaire Results

On the questionnaire, pilots were asked whether any of the IM Speed changes were unacceptable. The questionnaire wording used the term “speed commands” to refer to the IM Speeds. Results and pilot comments are in Table 4-22.

Table 4-22. Results for: “For the speed commands you received via AGD/CDTI displays, were any of the speed commands unacceptable?”

For the speed commands you received via AGD/CDTI displays, were any of the speed commands unacceptable?		
Option	**Replies**	**Pilot Comments**
Yes	10	(UPS919 Night 1) “Large variations (30 kts) in IAS after merge point.”
		(UPS919 Night 1) “250 @ BRRWN (240 was FMC limit).”
		(UPS857 Night 2) “1 Speed past M_{MO} at Top of Descent.”
		(UPS857 Night 2) “Over PXV In descent 291 KIAS (Over V_{MO}/M_{MO}). Speed commands inside of UPSCO was too high.”
		(UPS919 Night 2) “Would not give a speed even though we were 25 NM back – cmd spd was .80”
		(UPS919 Night 2) “Couldn’t keep speed, .79 => .84.”
		(UPS857 Night 3) “Numerous commands to M_{MO}.”
		(UPS903 Night 3) “Command at V_{MO}/M_{MO}. Speed change 65 knots during descent.”
		(UPS903 Night 3) “Some (commands) were to M_{MO} limits.”
		(UPS919 Night 3) “50 KTS variation.”
No	12	(UPS903 Night 2) Early on, we questioned a “high speed” command when spacing was already < 22nm. I think we just need to trust the timing more, instead of distance.”
		(UPS921 Night 3) “Speeds lagged & autoflight/autothrottles +/- 6 knots; more speed commands needed.”
		(UPS921 Night 3) “Speeds lagged, autoflight/autothrottles +/- 6/7 knots off.”
		(UPS905 Night 3) “Received some quite fast speeds in close -345 to 275. Ended up flying speeds to comply with CDA before AGD commanded a slower speed.”
Blank	2	(UPS905 Night 1) “No speed commands received.”
		(UPS905 Night 2) “Some did not agree with lineup of a/c initially, then OK.”

Pilots were also asked on the questionnaire, whether they were confident that the equipment gave them appropriate IM Speeds. The results are in Table 4-23.

Table 4-23. Results for: "Were you confident overall that the equipment was giving you appropriate speed commands?"

Were you confident overall that the equipment was giving you appropriate speed commands?		
Option	**Replies**	**Analysis Notes**
Yes	16	None
No	8	The "no" answers came primarily from the crews of UPS905 on Night 1, UPS919 on Nights 2 and 3, and UPS903 on Night 3. • The crew of UPS905 on Night 1 received only one IM Speed, likely due to an equipment setup issue. • The crew of UPS919 on Nights 2 and 3 did not feel the equipment was providing appropriate IM Speeds and often did not select IM Speeds. • The crew of UPS903 on Night 3 followed the IM Speeds closely, despite their noted misgivings.
Blank	1	None

4.9 Altitude Restriction Conformance

The altitude profiles for flights with SafeRoute data available were examined to determine if the IM-S AA operation had a negative effect on the ability of the flights to comply with the restrictions at BRRWN (at 11,000 ft), BRNBX (at or above 4500 ft), UPSCO (at 3000 ft), and PARCL (at 2400 ft). Figure 4-61 shows the altitude profiles across the flights against the crossing restrictions.

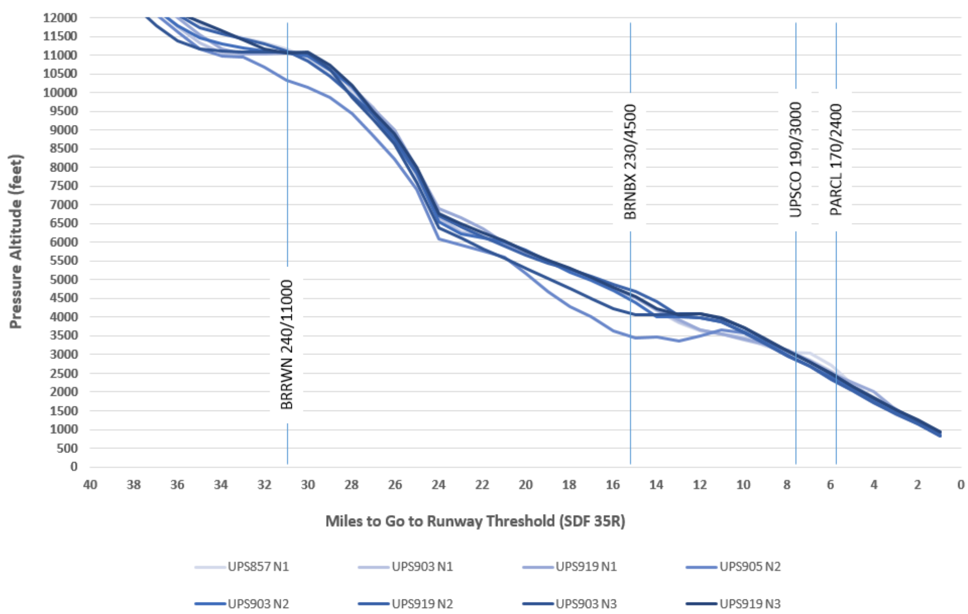


Figure 4-61. SafeRoute Aircraft Altitude Profiles and Crossing Restrictions

Nearly all of the flights appeared to be in conformance with the altitude crossing restrictions. UPS905 on Night 2 was the exception as it crossed BRRWN and BRNBX approximately 1000 ft below each restriction value. As described in Section 4.2.7, the crew apparently felt that the CDA was too steep, though it was unclear why. As this result was more attributable to the CDA procedure design, it did not appear that the IM-S operation negatively affected the crew's ability to comply with the published altitude restrictions.

4.10 Flight Deck Subjective Results

This section summarizes results for:

1. Flight Deck Compatibility and Operational Acceptability
2. Flight Deck Workload
3. Procedures and Crew Coordination
4. Communications
5. Head-down Time
6. Flight Deck Displays

Results in this section are based primarily on data collected from pilot questionnaires and from flight deck observer forms. MITRE, NASA Ames, and SBS recorded the observational data. MITRE developed the results summary and analyses. The questionnaire provided to pilots and flight deck observer forms are provided in Appendix A.

As described in Section 3.6, nineteen pilots participated in the evaluation. All were UPS management pilots; most had only limited prior line flights with IM-S AA. Their training primarily consisted of a computer-based training course, a checkride, and a field test training briefing. Some pilots flew the operation on more than one night and filled out a questionnaire for each event. These cases are noted in Table 4-21.

Two questionnaires were returned for each of the thirteen flights, resulting in an initial n of twenty-six. On Night 3, however, one pilot was erroneously given an older version of the pilot questionnaire. Because the questions were not the same as those given to the other pilots, this participant's data is not included in the results. As a result, n = 25 for most questions in the following sections. The following tables show the answers to the questions, including all of the pilot comments.

4.10.1 Compatibility and Operational Acceptability

The following questionnaire results refer to aspects of flight deck compatibility and operational acceptability. Results and pilot comments are in Table 4-24 and Table 4-25.

Table 4-24. Results for: "Was the spacing operation compatible with normal flight deck operations?"

Was the spacing operation compatible with normal flight deck operations?		
Option	**Replies**	**Pilot Comments**
Yes	23	(UPS857 Night 1) "CDA flap restrictions at BRNBX might offer unnecessary constraints."
		(UPS905 Night 3) "Keeping a flight path @ SPD intervene is a full time job –very manageable –but must keep up [with] aircraft. It was great to not talk & just fly a constant CDA."
No	1	(UPS903 Night 1) *No explanation given.*
Blank	1	(UPS903 Night 1) "One issue on descent is compression ==> the reduction from 19 NM spacing to 5 NM ==> this is distracting."

Table 4-25. Results for: "Would you have any objection to flying the spacing operation on a routine basis?"

Would you have any objection to flying the spacing operation on a routine basis?		
Option	**Replies**	**Pilot Comments**
Yes	1	(UPS919 Night 1) "Familiarity breeds comfort & safety. Ultimately, if we are going to do this, we need to do it all the time."
No	23	(UPS905 Night 1) "With repetition this would be easier & easier."
Blank	0	The PF of UPS919 on Night 3 answered "yes and no" with no explanation. The result is therefore not included in the above counts.

4.10.2 Workload

The following questionnaire results refer to aspects of flight deck workload. Results and pilot comments are in Table 4-26 and Table 4-27.

Table 4-26. Results for: "Did the spacing operation increase or decrease your workload?"

Did the spacing operation increase or decrease your workload?		
Option	**Replies**	**Pilot Comments**
Inc	17	(UPS903 Night 1) "Workload increases below 5000' AGL, speed, spacing, configuration."
		(UPS903 Night 2) "767 operates in a speed on pitch mode while in speed intervention. Maintaining path with command speed changes is work intensive."
Dec	1	(UPS857 Night 1) (PF) commented: "Have PF follow the CDA on EFB and PM follow the same on CDTI."
No Impact	7	None

Table 4-27. Results for: “Was your overall workload acceptable while conducting the spacing operation?”

Was your overall workload acceptable while conducting the spacing operation?		
Option	**Replies**	**Pilot Comments**
Yes	23	None
No	1	(UPS903 Night 1) *No explanation given.*
Blank	1	None

4.10.3 Procedures and Crew Coordination

The following questionnaire results refer to the clarity of IM-S AA procedures and crew coordination. Results and pilot comments are in Table 4-28 and Table 4-29.

Table 4-28. Results for: “Were the spacing operation procedures (e.g., initiation, conduct, and termination) clear?”

Were the spacing operation procedures (e.g., initiation, conduct, and termination) clear?		
Option	**Replies**	**Pilot Comments**
Yes	22	None
No	2	(UPS905 Night 2) *No explanation given.*
Blank	1	(UPS857 Night 1) “Termination could be more clear on the CDA → let the crew know that ~15 miles from field to stop following commands.”

Table 4-29. Results for: “Were you able to effectively coordinate spacing tasks with the other pilot?”

Were you able to effectively coordinate spacing tasks with the other pilot?		
Option	**Replies**	**Pilot Comments**
Yes	25	(UPS857 Night 1) (PF) commented: “Have PF follow the CDA on EFB and PM follow the same on CDTI.”
No	0	None
Blank	0	None

4.10.4 Communications with ATC

The following results refer to crew communications with ATC. Results are in Table 4-30.

Table 4-30. Results for: "Did you have any problems communicating with ATC about the spacing operation?"

Did you have any problems communicating with ATC about the spacing operation?		
Option	**Replies**	**Pilot Comments**
Yes	3	(UPS857 Night 1, UPS905 Night 2, UPS905 Night 3) *No explanation given.*
No	22	None
Blank	0	None

Ground and flight deck observers reported high pilot compliance with reporting "company spacing" on check-in. However, many pilots still reported "company spacing" in the manual pre-positioning phase (i.e., before coupling to the Target Aircraft and receiving IM Speeds). Also, there were several cases where pilots informed ATC they were "company spacing" when they were not in conformance with the IM Speeds. In at least one case (UPS919 Night 3), the crew clearly decided to stop complying with the IM Speeds and the ATC and flight deck observers did not note any instances of the pilots using "terminating company spacing" to inform ATC that they were no longer following IM Speeds. The use of "company spacing" when not in conformance with IM Speeds persisted even after crews were specifically briefed on the desired procedures.

4.10.5 Head-down Time

The following questionnaire results refer to pilot head-down time. Results are in Table 4-31 and Table 4-32.

Table 4-31. Results for: "Did the spacing operation increase or decrease your head-down time?"

Did the spacing operation increase or decrease your head-down time?		
Option	**Replies**	**Pilot Comments**
Inc	14	None
Dec	0	None
No Impact	11	None

Table 4-32. Results for: "Was your overall head-down time acceptable while conducting the spacing operation?"

Was your overall head-down time acceptable while conducting the spacing operation?		
Option	**Replies**	**Pilot Comments**
Yes	23	None
No	2	(UPS903 Night 2, UPS921 Night 3) *No explanation given.*
Blank	0	None

Although UPS903 on Night 2 noted an increase in head-down time, the UPS921 pilot on Night 3 answered that the spacing operation had no impact on head-down time. This suggests that the "unacceptable" response to head-down time was not a result of the spacing operation.

4.10.6 Flight Deck Displays

Most flight deck observers did not note any crew problems in setting up the CDTI to perform IM-S AA. However, the flight crew of UPS905 on Night 1 did not properly initiate the SafeRoute equipment and thus did not receive any IM Speeds. This confusion appeared to result from a misunderstanding of the functionality of the buttons used to navigate away from the IM-S AA setup page. The two choices were labeled "Complete" vs. "Save and Exit"; however, only "Complete" resulted in a coupling with the Target Aircraft and the generation of IM Speeds. The crew apparently selected "Save and Exit" which returned them to the CDTI page, but did not couple them to the Target Aircraft. Since they did not successfully initialize the SafeRoute system to receive IM Speeds, the crew chose to manually attempt to maintain 10 NM spacing throughout arrival.

Observers did not indicate that there was a notable overall crew preference for a particular method of selecting the target (target selection on CDTI vs. typing in ID in setup page). Observers reported that crews actively used the CDTI to determine range from aircraft around them – particularly during the manual setup phase.

Crews were asked on the questionnaire whether they thought the CDTI was required to perform the spacing operation after setup, and whether the IM Speed alerting was acceptable for getting their attention. Results are in Table 4-33 and Table 4-34.

Table 4-33. Results for: "Beyond setup, was the CDTI required to perform the spacing operation?"

Beyond setup, was the CDTI required to perform the spacing operation?			
Option	**Replies by Position**		**Pilot Comments**
	PF	**PM**	
Yes	6	7	None
No	7	5	
Blank	0	0	

Table 4-34. Results for: "Was the alerting for new speed commands acceptable for getting your attention?"

Was the alerting for new speed commands acceptable for getting your attention?		
Option	**Replies**	**Pilot Comments**
Yes	24	None
No	0	None
Blank	1	(Night 1 UPS905) responded N/A as they did not receive any IM Speeds.

During the conduct of the operation, no specific problems were observed or reported using the CDTIs.

4.11 ATC Subjective Results

Results in this section are based primarily on data collected from ATC observer forms. MITRE and SBS recorded the observational data. MITRE developed the results summary and analyses.

ATC facility data collection primarily consisted of observations and inferences made while watching controllers manage the traffic. Observers were given lists of questions to answer during and after the observation period; however, circumstances did not allow observers to give controllers questionnaires to fill out directly. Observers were sometimes able to speak with controllers during or after they managed the IM-S AA traffic, but this was not always the case. Consequently, results from the ground portion of the evaluation are subjective and qualitative in nature. The forms provided to ATC facility observers is provided in Appendix B.

The number of controllers involved in the test varied by facility and is noted in the individual sections. The following sections summarize the higher level observational data.

4.11.1 Kansas City Center

Since aircraft transitioned several ZKC areas during the IM-S AA period, the number of controllers observed varied. From the observer notes, the number is estimated at approximately 5 or 6 (2-3 for Prairie, 1 each for the Flint Hills, Ozark, and Gateway areas) per night. As described in Section

3.6, it is unknown whether individual controllers managed IM-S AA traffic for more than one event.

ZKC controller feedback was generally positive with no major problems or concerns noted. On Night 3, the observer reported that the general feeling was positive toward IM-S AA after seeing how “nicely” the IM-S AA flights were spaced. The observer noted that at least one controller positively commented directly on the spacing quality. The controllers monitored IM-S AA flights, without interventions any of the three nights. One controller on Night 2 noted that he believed IM-S AA worked well because IM-S AA flights had a separate stream. He did, however, wonder how difficult it would be to insert other non-IM-S AA flights into the IM-S AA stream. A controller on Night 3 concurred because he believed that it would “break the link” and disrupt the IM-S AA operation.

ZKC controllers appeared to have a basic understanding of the operational goal of IM-S AA and were generally comfortable with phraseology and communications. The observers noted reduced communications with the IM-S AA aircraft as opposed to the non-IM-S AA traffic. Two controllers noted that IM-S AA “made the job easy” and that it reduced radio calls.

On Night 1, UPS919 requested a climb to FL370. The Ozark controller managing the traffic asked the observer if this was acceptable per the goals of the operation. The observer said it was and the clearance to climb was granted. The controller later noted that it would be helpful to have the rules for altitude changes specified.

On Night 3, one of the controllers increased the speed of a non-IM-S AA aircraft and descended another in order to avoid conflict with IM-S AA aircraft. Two additional aircraft were vectored in another sector to allow the IM-S AA aircraft to continue unimpeded. The controllers reported having no issues with this.

4.11.2 Indianapolis Center

Since operations were combined into a single sector during the IM-S AA period, only one ZID controller per night managed the IM-S AA flow. As described in Section 3.6, it is unknown, however, whether the same controllers managed IM-S AA traffic for more than one night.

The controllers monitored IM-S AA flights and did not make any interventions on any of the three nights. On Night 1, the controller, when asked, noted no change in workload. However, controllers on the second and third nights noted to the observers that IM-S AA decreased frequency congestion and workload. The observers reported moderate transmissions with non-IM-S AA Flights and sparse transmissions with IM-S AA Flights across all three nights. Additionally, since the IM-S AA Flights were spaced far enough apart, the observer reported that ZID controllers were not concerned with the speed, spacing, or altitudes of the IM-S AA Flights on any of the three nights as separation was not an issue and aircraft would be delivered to the TRACON with sufficient spacing.

At least two of the controllers noted they would like to see more IM-S AA flights, but they were concerned that too many could create excessive en-route spacing, leading to long back-ups. It is possible, however, that they were blending OPD operations and the IM-S AA concept when they made this statement. None of the controllers felt that the IM-S AA flights adversely impacted the non-IM-S AA flights.

4.11.3 Louisville TRACON

Since operations were combined into a single sector during the IM-S AA period, typically only one TRACON controller per night managed the IM-S AA flow. As described in Section 3.6, it is unknown, however, whether individual controllers managed IM-S AA traffic for more than one event.

TRACON controllers were generally comfortable with the operation and phraseology, but noted concerns at times about faster-than-usual arrival groundspeeds. Though several of the flights crossed the fixes faster than the published SCRs, Table 4-14 shows only a few instances where the IM Speeds also higher than the SCR. As a result, it appeared that the higher actual (air)speeds across the fixes was not primarily due to the IM procedure.

At one point a controller felt spacing between two IM-S AA aircraft might be getting too close, but decided to wait to intervene. After further monitoring, the controller found the final spacing to be acceptable.

Overall it did not appear that the IM-S AA flights adversely impacted the non-IM-S AA traffic. However, the observer noted at least one occasion where a controller vectored a non-IM-S AA aircraft so that it would not interfere with the IM-S AA operation. There was also one non-IM-S AA aircraft that wanted a 35R approach, which the controller denied because the IM-S AA/OPD flights were allocated to 35R.

The controller on Night 2 noted that ATC cannot predict or know the altitudes of the IM-S AA aircraft on the OPD, so it was difficult to cross any traffic under or over that stream with the needed spacing. He noted that he would have liked to have had the expected speeds of the IM-S AA aircraft at the fixes along the OPD. The observer also reported that the controller on Night 3 noted that he would have liked to have had predicted altitudes; likely for the same reason. As shown in Figure 4-61, the aircraft were generally able to meet the altitude crossing restrictions, though one flight was under at BRRWN and two were under at BRNBX.

On Night 1, the controller did not issue any altitude clearances to the IM-S AA traffic, whereas he provided several clearances to the non-IM-S AA flights. The controller did not feel that the IM-S AA/OPD flights had any impact on his workload. On Nights 2 and 3, the controller did not specifically report any workload impact, but the observers believed that the controller appeared to monitor and communicate less with the IM-S AA flights as compared to the non-IM-S AA flights.

5 Discussion

The field test was the first known test of IM-S AA through OPDs with certified equipment and operationally approved procedures during revenue flights. Flight crews flew IM-S AA during OPDs and ARTCC and TRACON controllers maintained separation responsibility and monitoring the flights for any needed interventions. Previous research, some directly and some indirectly relevant, was drawn upon and used for this event. This section discusses the findings from the evaluation in terms of ATC considerations, IM Speed and flight deck subjective results, and spacing performance as a function of IM Speed conformance for the flights that had SafeRoute data available.

5.1 ATC Considerations

Controllers in this field test had a different role than in many of the past IM-S research activities. Though they did not initiate IM-S AA, they held coordination discussions with the UPS GOC, monitored the IM-S AA Aircraft, and managed any issues that arose. They used current ATC capabilities without the introduction of any new tools specific to IM-S AA. Off-nominal events were not planned and none arose during the field test. Therefore, no feedback or information was gathered from the controllers for such events.

For this version of IM-S AA as implemented by UPS, no major conceptual, human factors, operational, or safety issues (such as separation violations) were identified by ATC. This aligns with much of the past simulation and field work on IM-S AA, including that done in development activities for this implementation (Bone, et al., 2007; Penhallegon and Bone, 2009). The following paragraphs review the results and associated impact.

Once IM-S AA began and ARTCC controllers were monitoring the flights, no ATC interventions were deemed necessary with any of the IM-S AA aircraft in any of the three test event nights. That meant aircraft were able to remain on the OPD and also continue to conduct IM-S AA to deliver the ASG. Additionally, though it may have been a product of the unique operating environment, very few interventions were observed to be needed for aircraft conflicting with the IM-S AA operation. Based on the lack of interventions, it appears that some level of trust in and SA of the operation can be assumed or that spacing was sufficiently far away from the spacing / separation requirements such that intervention was not an issue. As evidence, there was at least one situation where the controller thought an intervention may be necessary but let the operation proceed. With close monitoring, the controller watched the situation resolve itself. Reduced interventions have been found in simulations and were noted as a benefit of IM-S AA (e.g., Grimaud, et al., 2001; Grimaud, et al., 2003; Aligne, et al., 2003; and Mercer, et al., 2005).

The ZKC and ZID ARTCC controllers were generally positive about the operation with no major problems or concerns noted. At least two ZKC and two Louisville TRACON controllers did wonder about how IM-S AA streams could be managed when operationally mixed with non-IM-S AA aircraft. The ZID controllers did not appear to share these concerns. However, neither facility experienced such an operation. An en route ATC IM-S HITL included situations in which non-IM-S Aircraft were inserted between an IM Aircraft and its Target. Controller participants found this to be an acceptable situation to manage (Peterson et al., 2012).

At least one ZKC controller was not sure whether altitude instructions would disrupt the operation. It was suggested that clarification be provided for the impact of altitude changes. It is expected that this would be part of the formal ATC training in future implementations.

Communications with IM-S AA flights were reduced to the procedure clearances and acknowledging the checking in phrase "Company Spacing" during frequency changes. Flight crews notifying each sector of their conduct of IM-S AA seemed to work well. There did appear to be some confusion about when to announce to ATC when starting and whether the set-up without IM Speeds was the point to announce "Company Spacing." Such confusion should be cleared up when ATC issues the IM Clearance and the flight crew acknowledges the receipt of that clearance. In this implementation, where the GOC provided the IM information, the operation was a bit more confused. If other similar operations are continued, training should clarify expectations.

Most en route controllers felt their overall workload and communications were decreased during the IM-S AA operation. Such a reduction in communications aligns with past research, especially for controllers receiving aircraft already conducting IM-S AA (e.g., Grimaud, et al., 2001). A reduction would be expected in this field test as the controllers did not issue the IM-S AA clearance / initiation information (based on this initial implementation), did not need to issue any speed instructions (based on the use of IM-S AA), and only needed other instructions when it was necessary for an intervention (of which there were none). The number of communications is already low due to aircraft being established on the OPD with speed and altitude constraints, and would be increased for the controller issuing the clearance / initiation information in future implementations. Based on past research (e.g., Grimaud, et al., 2001; Hebraud, et al., 2006; Peterson et al., 2012), it is expected that the increase in communication for some controller roles (e.g., initiation) would still be within acceptable levels.

The Louisville TRACON controllers were generally comfortable with the operation and phraseology. As with en route controllers, they did not make any interventions with IM-S AA aircraft on any of the three nights. Some TRACON controllers reported issues with not being able to predict or know the aircraft altitude on the OPD, making it difficult to cross any traffic under or over that stream. However, test results found that it did not appear that the IM-S operation negatively affected the crew's ability to comply with the published altitude restrictions. There were also subjective observations of faster than expected groundspeeds from the IM-S AA aircraft. These issues appear to be related to OPD procedures and not IM-S AA, but are relevant to this discussion when the operations are combined. As UPS only ran OPDs on an infrequent basis, it may have been difficult or impossible for the controllers to distinguish between issues related directly to OPDs versus those directly related to IM-S AA.

The TRACON controllers did not report any specific workload impact. The Night 1 observer noted that the TRACON controller did not appear to need to monitor the IM-S AA aircraft as much as non-IM Aircraft. The ability to tend to other tasks while aircraft are conducting IM-S AA has been noted as a benefit of IM-S that may allow the controller to handle more aircraft (Grimaud, et al., 2001) or simply direct attention to higher priority situations with an occasional check of IM-S AA that is behaving predictably (Hebraud, et al., 2006). This same controller did not issue any altitude clearances to the IM-S AA traffic on the OPDs whereas he did give clearances to the non-IM flights to avoid the aircraft on the OPDs. On Nights 2 and 3, the observers believed that the TRACON controllers appeared to monitor and communicate less with the IM-S AA flights as compared to the 35L arrivals. The exact reasons for the decreased monitoring were unclear.

Controllers at times also noted faster-than-usual arrival groundspeeds during the OPDs. Fifteen out of 33 possible instances were observed during the test where actual IM Aircraft airspeeds exceeded the OPD SCRs. However, there were only 4 out of 33 observed cases where both the IM Speed *and* the actual aircraft speed were in excess of the SCR value plus 10 kts. This leaves 11 cases in which the IM Speed was not in conflict with SCR, while the actual speed exceeded it. The reasons for these 11 cases were not directly observed. It is known, however, that the IM speed guidance used for this test did not have knowledge of the IM Aircraft's deceleration capability and therefore simply attempted to match the deceleration profile of the Target Aircraft. It seems likely that the IM Aircraft may not have been able to match the Target Aircraft's deceleration rate and, as a result, started its deceleration with insufficient time and space available to achieve the speed needed at the SCR. Similar cases were also noted by Dao, et al. (2010), who found that pilots had energy management issues when entering IM Speeds into the MCP (versus direct input from the FIM equipment into the autoflight system) to fly IM-S AA during OPDs into SDF in a desktop PC Boeing 747 simulator. Further research may be needed in this area to determine if OPD design should take into account IM-S AA operations to satisfy the goals of both operations or if this specific OPD could use a redesign regardless of IM-S AA. Hoffman, et al. (2007) stated that design modifications should be considered to achieve a continuous descent.

5.2 IM Speed and Flight Crew Subjective Results

For this version of IM-S AA as implemented by UPS, with the possible issue of IM Speeds that increase aircraft speed during descent, no major conceptual, human factors, or operational issues were identified by pilots. Based on results from the pilot questionnaires, nearly all pilots reported that IM-S AA was compatible with normal flight deck operations and that they would have no objection to conducting the IM-S operation on a routine basis. Pilots were almost evenly split on whether the CDTI was required to perform IM-S AA beyond setup. However, based on past work and the results of this field test, the CDTI graphical display of traffic does appear to be a useful tool for flight crews.

All pilots felt they were able to effectively coordinate spacing tasks within the cockpit. Of the twenty-three pilot responses, 15 noted a workload increase with IM-S AA and thirteen noted an increase in head-down time as compared to non-IM-S AA operations. However, the vast majority of pilots rated their overall workload and head-down time as acceptable and it is possible that further training and experience with the operation may make the increases negligible. Follow-on IM-S AA research might examine whether increases in workload and head-down time would be less acceptable to pilots in different environments or, by the time the operation is available in more complex environments, if advances in equipment, algorithms, and procedures effectively reduce IM-S AA workload and head-down time.

Nearly all pilots felt the operational procedures were clear; however, there were several cases where pilots informed ATC they were "company spacing" when they were not in conformance with the IM Speeds. In at least one case (UPS919 Night 3), the crew clearly decided to stop selecting the IM Speeds. Across all of these situations, observers did not note any instances of the pilots using "terminating company spacing" to inform ATC that they were no longer following IM Speeds. This is consistent with findings from Bone, et al. (2008a) and Bone, et al. (2008b), which observed ambiguity in flight crew expectations of ATC responsibilities in the event of off-nominal terminations. Especially in cases where crews are performing an IM-S AA operation in the presence of fix crossing restrictions, lack of conformance with the IM Speeds may not necessarily be appropriate as the sole automatic grounds for crews to announce that they are terminating spacing. As such, crews likely need information to help them to determine whether or not they are conforming to an IM clearance beyond just how closely they comply with the IM Speeds. Consistent with recommendations from past HITL research, clear communications procedures with ATC regarding on-going conduct and termination should be established and trained.

Nearly all pilots felt the SafeRoute (visual) alerting scheme was acceptable for bringing their attention to a new IM Speed and two thirds of the pilot responses indicated they were confident overall that they were being presented with "appropriate" IM Speeds. However, the negative responses suggest that further consideration should be given to providing pilots sufficient information to trust the algorithm speed guidance.

Most crews were comfortable with the frequency of IM Speed changes they experienced during the test. During the IM-S AA period, crews received on average an IM Speed change approximately every five minutes. Since the number of IM Speeds during the Achieve Phase was low, across the flights, the IM Speed changed on a per flight basis on average between every seven and every 36 minutes during the IM-S AA Achieve Phase. In the Maintain Phase the IM Speed changed on a per flight basis on average between every 100 and every 180 seconds. Most crews reported that they were comfortable with this rate. For the IM Speeds that were selected, all but one were responded to within 60 seconds. The average response time for all IM Speeds that were selected in 60 seconds or less was 11 seconds.

During the descent, the vast majority of IM Speed changes were less than 10 kts in magnitude relative to both the previous IM Speed and current SEL. The IM Speeds with magnitude change differences greater than 30 kts were observed mainly during the BRRWN Restriction and Final Descent Phases. Normally IM Speed acceptability is assumed in the context of too many IM

Speeds, e.g. a greater number of IM Speeds is considered less desirable than a fewer number. However, two pilots noted that their number of IM Speeds was unacceptable as *not enough* were received, resulting in large magnitude change jumps. They would have preferred *more* IM Speeds to maintain a smoother speed profile. The magnitudes of the IM Speed changes (relative to SEL) for one of the pilots did not appear to be any greater than those experienced by other crews; however, the other pilot did appear to be presented with larger IM Speed change magnitudes than other crews. The crew of the other flight to experience IM Speed changes of similar magnitudes did not report the number of IM Speeds to be unacceptable. Despite this, the tradeoff between number of IM Speeds and resulting magnitude change jumps should continue to be considered in future algorithm development activities.

Flight crews initiated speed changes independently of the IM Speed for several reasons, depending on where they were in the Maintain Phase. One of the most common reasons was crews managing their deceleration into the SCR at BRRWN independent of the IM Speed value. Though six (of 12) crews appeared to exactly comply with each of their IM Speeds during the BRRWN Restriction Phase, four crews initiated the speed reduction before the IM Speed value started to decrease. It is unknown whether they were aware that the FIM equipment was constrained to limit IM Speeds to 250 kts below 11,000 ft. Two other crews were observed to wait for the first slow-down IM Speed before reducing SEL, but they then selected 240 kts instead of following the step-down IM Speeds. Since the IM Speed values stepped down in increments, the crews initiating their own speed reductions saw IM Speeds suggesting that the aircraft increase speed. As crews exhibited a range of behaviors relative to IM Speed changes at BRRWN, further development into algorithm management of large speed decreases is recommended.

Not selected IM Speeds in the Arrival Turn and Final Descent Phases, and crew-initiated speed reductions to FAS, do not appear to be related to conflicts between the IM Speed and the SCRs at BRNBX, UPSCO, and PARCL. Since crews were instructed to fly no faster than 10 kts of the published CDA speeds even if IM Speeds were different, situations were possible in which the crew would have had to not select the IM Speed and/or initiate their own speeds in order to comply. Of the 30 fix crossings which exclude instances where PARCL was outside the IM-S AA period, there were only four instances where crews appeared to not select an IM Speed in order to comply with an SCR. Two of the four occurred when the IM Speed was within the SCR tolerance, yet crews elected to select the exact value of the SCR. As such, it does not appear that the SCRs had a large overall impact on crew compliance and conformance with IM Speeds. Crews instead appeared to control aircraft speeds more with regard to following the IM Speeds or managing their energy as they saw appropriate.

Crews in the Arrival Turn and Final Descent Phases also had to balance IM Speeds against final configuration changes for landing. Many crews stepped down SEL to reduce speed below 200 kts and performed final speed reductions to FAS independent of the IM Speeds (as would be expected). For most flights, the reductions in IM Speed below 200 kts occurred either before crews were ready to begin their final deceleration to FAS, or after crews had already started reducing. In only a few cases did the crews reduce speed below 200 kts on the same schedule as the IM Speed reductions. Overall, flight deck workload is high at this point as crews configure the aircraft and prepare for landing. Although pilots rated workload overall with IM-S AA as acceptable, the operation required them to evaluate the IM Speeds being presented during this time and whether they were compatible with the speed crossing restrictions and flap deployment schedule. Consideration should be given to the operational compatibility of IM Speeds with aircraft and procedure limits during the final portion of the descent and approach.

IM Speed trend changes did not appear to be a significant issue during this evaluation. The majority of the IM Speed trend changes were a result of initially providing speed-up IM Speeds during the Achieve and/or Initial Descent Phases, then requiring the aircraft to slow in response to a decrease in the lead aircraft speed at BRRWN. Three trend changes clearly resulted from reversing the spacing performance opening or closing trends to maintain the ASG. Five of 19 trend changes were unclear of purpose; i.e., the result of the trend did not appear to be consistent with increasing or decreasing spacing in a desired direction, or no spacing performance data was available.

The process of getting IM Aircraft into position behind a Target Aircraft at the appropriate spacing to start the OPD proved to be challenging for flight crews. This is not typically a flight crew task, nor should it be, but was done for this field test so the setup would be relatively transparent to ATC. Considerable cockpit-to-cockpit coordination was required to get aircraft into position. It was recognized early on in this IM-S AA implementation that setting up the aircraft could be workload intensive for whoever was trying to do that task (e.g., controllers, or the GOC in coordination with the flight crews) and that a ground setup capability would provide a significant advantage.

5.3 Spacing Performance and IM Speed Conformance

Spacing performance in time was available for each of the SafeRoute flights. The difference between current time spacing and the ASG was used to determine spacing performance and how it related to IM Speed conformance. As noted earlier, conformance is the degree to which the SEL speed matched the IM Speed over the IM-S AA period. This provides a reasonable overall indication of crew intent to follow the IM Speeds.

As described in Section 4.2, IM Speed conformance is defined as “high” if the SEL speed was exact or within M0.01 or 5 kts of the IM Speed at least 80% of the phase. Conformance is defined as “medium” if SEL was within M0.02 or 10 kts of the IM Speed at least 50% of the phase. Conformance is also defined as “high” or “medium” if it could be determined from the actual speed data that crews were attempting to comply with the IM Speeds through means other than SEL. Conformance is otherwise defined as “low.” Table 5-1 summarizes IM Speed conformance and spacing performance for the flights that had SafeRoute data available. The table includes the Achieve Phase and the four Maintain sub-phases. The tables also provide the overall spacing performance and final spacings when each IM Aircraft’s Target Aircraft touched down.

Table 5-1. IM Speed Conformance / Spacing Performance Summary

Night	IM-S Flight	IM Speed Conformance	Spacing at Achieve-by Point Relative to ASG (sec)	IM Speed Conformance Spacing Mean (x) and Standard Deviation (SD) (Seconds, relative to ASG)				Average Maintain Spacing Relative to ASG (sec)	Spacing Relative to ASG at TGT TD (sec)
		Achieve		Initial Descent	BRRWN Restriction	Arrival Turn	Final Descent		
1	UPS857	High	+4	High x = 5.3 SD = 1.2	Low x = 6.0 SD = 0.8	Medium x = 1.3 SD = 1.4	Medium x = -1.2 SD = 2.1	x = 3.0 SD = 3.0	-6
1	UPS903	High	-1	High x = 1.3 SD = 2.1	High x = 2.3 SD = 0.5	Medium x = -0.5 SD = 2.1	Medium x = 2.7 SD = 3.7	x = 1.0 SD = 2.5	-7
1	UPS919	High	+1	High x = 5.8 SD = 2.2	High x = 0.9 SD = 2.4	High x = 1.4 SD = 1.0	Medium x = 3.7 SD = 0.9	x = 2.5 SD = 2.7	+2
2	UPS905	Medium	+1	High x = 7.9 SD = 1.1	Medium x = 4.6 SD = 0.2	Medium x = 5.3 SD = 3.6	Low x = 30.5 SD = 9.0	x = 9.5 SD = 8.8	+46
2	UPS903	High	-5	High x = 0.7 SD = 2.4	High x = -1.9 SD = 1.0	High x = -1.9 SD = 1.0	High x = -4.7 SD = 1.0	x = -1.2 SD = 2.7	-8
2	UPS919	High	+22	Low x = 14.5 SD = 1.1	Medium x = 13.8 SD = 0.2	Medium x = 7.6 SD = 3.2	Medium x = -1.4 SD = 1.3	x = 9.7 SD = 6.0	-3
3	UPS903	High	+6	High x = 5.3 SD = 1.3	Low x = 2.6 SD = 0.6	High x = 5.4 SD = 0.9	Medium x = -0.8 SD = 3.1	x = 4.2 SD = 2.7	-8
3	UPS919	Medium	+4	Low x = 8.9 SD = 4.3	Low x = 24.5 SD = 2.5	Low x = 38.6 SD = 7.0	Low x = 48.8 SD = 0.4	x = 25.6 SD = 16.2	+49

Flight crews showed mostly high conformance with IM Speeds during the Achieve Phase, as would be expected in an environment with relatively low workload, no potentially contradictory procedural speeds, relative constant speed of ownship, and a limited number of IM Speeds. All but one aircraft achieved the ASG within +/- 6 seconds. This is comparable spacing performance to that observed by Lohr et al., (2005), in which the ASG of 90 seconds was achieved with an average of 90.8 seconds and a standard deviation of 7.7 seconds.

UPS905 Night 2 and UPS919 Night 3 showed medium overall conformance in this phase yet still achieved a spacing very close to the ASG. In these cases, the flights showed better conformance later in the Achieve Phase, which appeared to be sufficient time to close to achieve an interval near the ASG by the achieve-by point. This suggests that higher conformance to IM Speeds seems to have the most direct impact on final spacing performance if it occurs close to the point of measurement. Lower conformance, further from the point of measurement, appears to have less impact on final spacing performance.

In contrast, the crew of UPS919 on Night 2 showed high overall conformance, but crossed the achieve-by point 22 seconds outside of the ASG. In this case it appeared that since the aircraft was already flying at the IM Speed cap of M0.84, no further speed-up IM Speeds could be provided to the crew that would have reduced the spacing at the ASG. Its Target Aircraft, UPS903, was flying KIAS which was bounded by the Maximum Allowable Speed received from its ADC. As a result, UPS903 was complying with a KIAS IM Speed that translated into M0.85. If it had flown Mach during the Achieve Phase, it is likely its IM Speed would also have been bounded at M0.84. This might have allowed UPS919 to achieve a more accurate spacing at the achieve-by point. The impact on IM performance of airspeed and Mach limitations as they apply to dissimilar airframes should be given further consideration.

Table 5-1 also shows that after TOD, five of the eight flights with available SafeRoute data were able to maintain the ASG within +/- 10 sec. Their final spacings, i.e. when their Target Aircraft touched down, were within 8 sec of the ASG. These five flights showed mostly high-to-medium IM Speed SEL conformance across each of the Maintain sub-phases. This is consistent with fast time simulations, which have demonstrated inter-arrival times within +/- 10 seconds at the runway threshold for aircraft flying OPDs (Weitz et al., 2005).

A sixth flight, UPS919 on Night 2, also showed spacing performance within +/- 5 seconds of the ASG during the Final Descent Phase and at the time of Target Aircraft Touchdown. Their reduced overall accuracy in the Maintain Phase was due to crossing the achieve-by point 22 seconds outside of the ASG for reasons discussed earlier. They showed medium SEL conformance with the IM Speeds during the descent and were able to finish the operation with spacing only three seconds inside the ASG.

Two flights exhibited lower IM Speed conformance during the descent and had final spacings 46 and 49 seconds outside of the ASG. The specifics of these flights were provided in Section 4.2, but the lack of conformance is briefly reviewed here as well.

A sharp rise in spacing occurred for UPS905 on Night 2 in the Arrival Turn Phase after the turn at the JMCSY waypoint. Despite the IM Speed appearing to attempt to close the gap with the Target Aircraft, the crew appeared to place a higher priority in meeting the later crossing restrictions. During the initial speed reduction, the observer noted that “the crew feels CDA is too steep and thus they are carrying too much speed.” It is unclear, however, how the crew came to this determination as they crossed BRNBX 20 kts slower than its SCR. This crew also appeared to step down to FAS earlier than other flights, which caused them to continue to lose spacing. The crew then did not select the high IM Speed that was attempting to close the gap during the Final Descent Phase, and the final spacing for this flight was higher than for all but one of the other flights.

UPS919 on Night 3 also began to open up spacing during the Maintain Phase. The crew elected not to comply with the IM Speeds and noted that they did not feel it was appropriate to accelerate after TOD – especially with a large magnitude speed up that they reported would have brought them close to Max Operating Speed / V_{MO}. Their overall SEL and actual speed conformance was low throughout the Maintain Phase, and their final spacing was the highest of all the flights. The reason for the increased spacing that resulted in the speed-up IM Speeds is unclear, though it could possibly be due to the behavior of the Target Aircraft. The UPS919 Night 3 crew noted that the FIM equipment commanded the “maximum” speed even they were less than 20 miles from the Target Aircraft at TOD. The crew further explained that they lost spacing because the Target Aircraft (UPS905) kept up “its speed up during the descent and was not at 240 IAS when it passed the first waypoint.” This appears to be consistent with the UPS905 Night 3 speed profile; however, SafeRoute data was not available for that flight, precluding further investigation into the cause.

Overall, flights that showed higher IM Speed conformance during the Maintain Phase, especially later in the descent, achieved final spacings closer to the ASG than flights with lower conformance. This suggests a validation of the simulation results described in Bone, Penhallegon, and Stassen (2008a), in which lower spacing variance was observed with flight crew speed guidance than without. Since it appears possible for IM-S AA aircraft to still achieve final spacings close to the ASG despite medium overall conformance, there should be procedural consideration given to how much latitude crews have in conforming to the IM Speed before they are required to notify ATC and/or terminate.

6 Conclusions and Recommendations

The 2010 IM-S AA Field Test was the first known test of an IM-S AA implementation using OPDs with certified equipment and operationally approved procedures during revenue flights. It built upon previous experience in IM simulations (e.g., NASA, MITRE, EUROCONTROL) and initial field operations (i.e., UPS, ACSS) and was intended to demonstrate the viability of the concept for maturing and validating relevant portions of IM-S documentation. The test also provided field validation of the operational application, as well as field data to support standards development and benefits analysis. As a culmination of years of development activities and preliminary field flights, the specific research objectives were to examine the IM-S AA concept, phraseology, ATC and flight crew procedures and tools, as well as algorithm outputs and interval delivery at significant points.

Per the research objectives, key findings include:

- For the implementation of IM-S AA as implemented by UPS, no major conceptual, human factors, or operational issues were identified by ATC or pilots. Test participants were generally comfortable with the operation, procedures, and workload.
- Once IM-S AA had begun, no ATC interventions were made with any of the IM-S AA aircraft across all three test nights. Several controllers noted that the IM-S AA traffic resulted in less workload and communications than the non-IM-S AA traffic.
- Across the flights, the IM Speed changed on a per flight basis on average between every seven and every 36 minutes during the Achieve Phase. In the Maintain Phase the IM Speed changed on a per flight basis on average between every 100 and every 180 seconds. Most crews reported that they were comfortable with this rate, though two pilots noted that they would prefer more, smaller magnitude IM Speed changes than what they experienced. Except for one case, flight crews selected IM Speeds within 11 seconds of the display change.
- Pilots showed mostly high conformance following the IM Speeds in the Achieve Phase and all but one aircraft achieved the ASG at the achieve-by point within +/- 6 seconds.
- In the Maintain Phase, five of the eight flights with available SafeRoute data showed mostly high-to-medium IM Speed conformance and were able to maintain the ASG within +/- 10 sec throughout the phase. Their final spacings, i.e. at the time their Target Aircraft touched down, were all within +/- 8 sec of the ASG. A sixth flight started the Maintain Phase 22 sec outside of the ASG. However, the flight crew showed medium conformance with the IM Speeds and were able to make up the spacing during descent. Final spacing was within 3 seconds of the ASG at the time of Target Aircraft Touchdown.
- The two flights that exhibited low IM Speed conformance during the latter part of the Maintain Phase exhibited final spacings 46 and 49 seconds outside of the ASG. Flight crew comments suggest a reluctance to select IM Speeds that increase aircraft speed during descent.

- During the operation, pilots also flew some speeds independent of IM Speeds, which was expected. One of the main reasons was when crews performed speed reductions to comply with crossing restrictions and to step down to the final approach speed, independent of the IM Speeds.
- The IM-S operation did not appear to negatively affect the crew's ability to comply with published altitude restrictions.
- No significant problems were reported by pilots in using the displays to perform IM-S AA. However, one crew had an issue choosing the correct option to engage the operation. This was due to confusion with meaning of button labels, and unfortunately led to the inability start IM-S AA for that aircraft. Opportunities for this error were noted in the past. A design / label change should be considered.
- No major issues were noted with phraseology and communications, although there appeared to be some cases where flight crews may have needed to inform ATC of terminating company spacing. These were either cases where the flight crews communicated within the cockpit their intention not to follow IM Speeds, or when the flight crew was not selecting each IM Speed. The lack of informing ATC may have been related to several issues associated with the field test. However, as seen in the MITRE HITL simulations, clear communications procedures with ATC regarding on-going conduct and termination should be established and trained.

The field evaluation also identified several potential issues for further concept development. First, further study is recommended for the interactions between OPD energy management, including speed constraints, and IM Speed conformance including accelerations during descent. In particular, further development into algorithm management of large speed decreases (e.g. to comply with speed crossing restrictions) is recommended. Consideration should be given to the operational compatibility of IM Speeds with aircraft and procedure limits during the final portion of the descent and approach. These and past research results show flight crews will make operational decisions to not follow every IM Speed and will enter speeds independent of IM Speeds. It is important to understand why such deviations occur and the impact on achieving and maintaining the assigned spacing goal.

Additionally, when ATC issues the IM-S AA clearance, lack of conformance with the IM Speeds is not appropriate as the sole automatic grounds for crews to announce that they are terminating spacing. Since it appears possible for IM-S AA aircraft to achieve final spacings close to the ASG despite medium overall conformance, there should be consideration given to how much latitude crews have in conforming to the IM Speed before they are required to notify ATC and/or terminate. The flight crew may need to make operational decisions to not select an IM Speed, which should be acceptable as long as they conform to the IM clearance. However, crews may need information to help them to determine whether or not they are conforming beyond just whether they select every IM Speed. Training materials should specifically cover and reinforce situations for when and how to announce IM-S AA status (especially terminations) to ATC. Consideration should also be given to the appropriate IM-S AA initiation location, given that conformance to the IM Speeds appears to have less impact on final spacing performance the farther away it is from the point of measurement.

The results from this field evaluation helped validate past fast-time and HITL simulation results that suggest overall concept acceptability and feasibility. The overall activities leading up to and including this field test (e.g., concept description, safety analysis, preliminary performance analysis, data collection in simulation and line operations, etc.) added to the data available related to IM-S AA. The activities provided a foundation for IM avionics standards and also helped to validate the operational concept and past fast-time and HITL simulation results. The field test data should also inform the development of display and other system requirements as further FAA flight testing and Minimum Operational Performance Standards (MOPS) are developed. Finally, the data should help with the determination of IM-S AA benefits by establishing performance data that can be used as parameters for future modeling and simulation research.

7 References

ADS-B In Aviation Rulemaking Committee (2010). *Interval Management (IM) and CDTI Enabled Delegated Separation (CEDS) operational applications, v1.1.* December 21, 2010.

Aligne. F., Grimaud, I., Hoffman, E., Rognin, L., and Zeghal, K. (2003). *CoSpace 2002 controller experiment assessing the impact of spacing instructions in E-TMA and TMS*. Eurocontrol report No 386, Volume 1. Bretigny-sur-Orge, France: EUROCONTROL Experimental Centre.

Battiste, V., Ashford, R. and Olmos, B. O. (2000). *Initial evaluation of CDTI / ADS-B for commercial carriers: CAA's Ohio River Valley Operational Evaluation.* Proceedings of the 5th World Aviation Congress and Exposition, San Diego, CA, October 2000. SAE Paper Number 2000-01-5520. Warrendale, PA: SAE International.

Baxley, B. T., Hubbs, C., Shay, R., and Karanian, J. (2011). *Use of data comm by flight crew to conduct interval management operations to parallel dependent runways.* In the Proceeding of the 11th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Virginia Beach VA, September 2011. Reston, VA: AIAA, Inc.

Benson, L. M., Peterson, T. N., Orrell, G. L., and Penhallegon, W. J. (2011). *Ground-based Interval Management-Spacing (GIM-S AA) controller information requirements human-in-the-loop simulation*. MTR110213. McLean, VA: The MITRE Corporation.

Bone, R.S., and K.M. Long. (2014). *Flight Crew and Air Traffic Controller Interactions when Conducting Interval Management Utilizing Controller Pilot Data Link Communications*. MTR130300R1. McLean, VA: The MITRE Corporation

Bone, R. S. and Penhallegon, W. J. (2006). *Flight Deck-Based Merging and Spacing Demonstration on July 6, 2006: Initial Federal Aviation Administration (FAA) Examination of a Planned Cockpit Implementation*. MTR 06W0000072. McLean, VA: The MITRE Corporation.

Bone, R. S., Penhallegon, W. J., and Stassen, H. P. (2008a). *Flight Deck-based Merging and Spacing during continuous descent arrivals and approach: Impact on Pilots. FDMS 3 Simulation. February - March 2007*. MTR 080208. McLean, VA: The MITRE Corporation.

Bone, R. S., Penhallegon, W. J., and Stassen, H. P. (2008b). *Flight Deck-based Merging and Spacing (FDMS) impact on flight deck en route operations: FDMS 2 Simulation. August - September 2006*. MTR 080034. McLean, VA: The MITRE Corporation.

Bone, R. S., Penhallegon, W. J., Stassen, H. P., Simons, E., and DeSenti, C. (2007). *Flight Deck-based Merging and Spacing (FDMS) impact on en route air traffic control operations: FDMS 1 Simulation. May - June 2006*. MTR 070071. McLean, VA: The MITRE Corporation.

Boursier, L., Cloarec, D., Favennec, B., Hoffman, E., Gordon, R., Vergne, F., and Zeghal, K. (2005). *CoSpace 2004 ground experiment: Sequencing arrival flows with spacing instructions and arrival manager*. Bretigny-sur-Orge, France: EUROCONTROL Experimental Centre.

Boursier, L., Hoffman, E., Rognin, L., Trzmiel, A., Vergne, F., and Zeghal, K. (2006). *Airborne spacing in the terminal area: a study of non-nominal situations.* Proceedings of the 6th AIAA Aviation Technology, Integration and Operations Conference (ATIO), Wichita, Kansas, September 2006. Reston, VA: AIAA, Inc.

Callantine, T. J., Palmer, E. A., Homola, J., Mercer, J. M., and Prevot, T. (2006). *Agent-based assessment of trajectory-oriented operations with limited delegation.* Proceedings of the 2006 IEEE/AIAA 25th Digital Avionics Systems Conference, Portland, OR, October 2006. Piscataway, NJ: IEEE Press.

Clarke, J. P., Bennett, D., Elmer, K., Firth, J., Hilb, R., Ho, N., Johnson, S., Lau, S., Ren, L., Senechal, D., Sizov, N., Slattery, R., Tong, K., Walton, J., Willgruber, A., and Williams, D. (2006). *Development, design, and flight test evaluation of a continuous descent approach procedure for nighttime operation at Louisville International Airport*, Report of the PARTNER CDA Development Team, Report No. PARTNER-COE-2006-02. Available at http://www.mit.edu/people/liling/files/cda_rpt.pdf.

Cloarec, D., Purves, K., and Vergne, F. (2004). *CoSpace 2003 controller model based study: Assessment of airborne spacing tasks in the extended TMA*. EUROCONTROL report No 392. Bretigny-sur-Orge, France: EUROCONTROL Experimental Centre.

Dao, A-Q. K., Lachter, J. B., Battiste, V., Brandt, S. L., Vu, K-P, Strybel, T. Z. Ho, N., Martin, P. and Johnson, W. W. (2010) *Automated spacing support tools for Interval Management operations during continuous descent approaches,* Human Factors and Ergonomics Society Annual Meeting Proceedings (Vol. 54, pp. 21–25).

Erkelens, L. J. J. (2000). *Research on noise abatement procedures*. NLR TP 98066. Amsterdam, Netherlands: NLR.

EUROCAE (2015). *Safety, Performance and Interoperability Requirements Document for Airborne Spacing—Flight Deck Interval Management (ASPA-FIM).* ED195 Rev A. Malakoff France: EUROCAE.

EUROCONTROL (2006). *CoSpace 2005-ASAS Sequencing and Merging: Flight deck user requirements, version 2.1*.

FAA (2000). *Operational Evaluation-1 final report*, Department of Transportation Federal Aviation Administration Safe Flight 21 Program Office, AND-510. Washington, DC: DOT FAA.

FAA (2001). *Operational Evaluation-2 final report*. Cargo Airline Association (CAA) ADS-B Program and FAA Safe Flight 21 Program. Washington, DC: DOT FAA.

FAA (2005). *Technology development future surveillance. SDF metrics update - January 2005*. Washington, DC: DOT FAA.

FAA (2006). *Flight Deck-Based Merging and Spacing (FDMS) implementation releases 1 and 2: Application description, version 1.4*, August 2006. Bone, R. (ed.). Washington, DC: DOT FAA.

FAA (2007). *ATO-E Surveillance and Broadcast Services Benefits Basis of Estimate*. FAA-2007-29305-0013 1. Washington, DC: DOT FAA.

FAA (2008). *Flight Deck-Based Merging and Spacing (FDMS) initial implementation: application description version 2.1*, February 2008. Bone, R. (ed.). Washington, DC: DOT FAA.

FAA (2015). *Concept of Operations for ADS-B In Interval Management – Spacing (IM-S) Arrivals, Approach, and Cruise (AA&C).* SBS-089 Rev. 02. Washington, DC: DOT FAA.

FAA/EUROCONTROL Cooperative Research & Development. (2001). *Principles of operation for the use of airborne separation assurance systems, Version 7.1*, 15 June 2001. Available at: http://adsb.tc.faa.gov/RFG/po-asas71.pdf

Garloch, J. L. (2001). *Flight testing of a prototype cockpit display of traffic information for approach spacing applications.* Proceedings of the 2001 IEEE / AIAA 20th Digital Avionics Systems Conference, Daytona, Beach, FL, October 2001. Piscataway, NJ: IEEE Press.

Green, S. M., and Grace, M. P. (1999). *Conflict-free planning for en route spacing: A concept for integrating conflict probe and miles-in-trail.* AIAA Guidance, Navigation, and Control Conference and Exhibit. Reston, VA: AIAA, Inc.

Grimaud, I., Hoffman, E., Rognin, L, and Zeghal, K. (2003). *EACAC 2001 real-time experiments: initial evaluation of limited delegation of spacing to the flight deck*. EUROCONTROL report No 380. Bretigny-sur-Orge, France: EUROCONTROL Experimental Centre

Grimaud, I., Hoffman, E., Rognin, L, Zeghal, K., and Deransy, R. (2001). *EACAC 2000 real-time experiments: initial evaluation of limited delegation of separation tasks to the flight deck*. EUROCONTROL report No 368. Bretigny-sur-Orge, France: EUROCONTROL Experimental Centre.

Hebraud, C., Hoffman, E., Papin, A., Pene, N., Rognin, L., Sheehan, C., and Zeghal, K. (2004). *CoSpace 2002 flight deck experiments assessing the impact of spacing instructions from cruise to initial approach*. EUROCONTROL report No 388, Volumes I and II. Bretigny-sur-Orge, France: EUROCONTROL Experimental Centre.

Hebraud, C., Hoffman, E., Pene, N, Rognin, L., Sheehan, C., and Zeghal, K. (2004). *CoSpace 2003 flight deck experiment assessing the impact of spacing instructions from cruise to final approach*. EUROCONTROL report No 397, Volume 1. Bretigny-sur-Orge, France: EUROCONTROL Experimental Centre.

Hebraud, C., Martin, J. L., Leone, M., and Troise, O. (2006). *Validation of a European gat to gate operational concept for 2005- 2010, Version 1.1*. Brussels, Belgium: EUROCONTROL.

Hoffman, E., P., Martin, T., Pütz, A., Trzmiel, A., and Zeghal, K. (2007). *Airborne spacing: Flight deck view of Continuous Descent Approach (CDA).* Proceedings of the 7th American Institute of Aeronautics and Astronautics (AIAA)Aviation Technology, Integration and Operations Conference (ATIO), Belfast, Northern Ireland, UK, September, 2007. Available at: http://www.eurocontrol.int/eec/public/standard_page/LIB_Conf_2007.html in ‘t Veld, A. C., van Paassen, M. M., Mulder, M., and Clarke, J. P. (2003). *Pilot support for self-separation during decelerating approaches.* In R. S. Jensen (Ed.) Proceedings of Twelfth International Symposium on Aviation Psychology, Dayton, Ohio.

Ivanescu, D., Shaw, C., Hoffman, E., and Zeghal, K. (2005). *Design of an airborne spacing director to minimise pilot speed actions.* Proceedings of the 6th USA / Europe Air Traffic Management R&D Seminar, Baltimore, USA, June 2005. Available at: http://www.atmseminar.org/papers.cfm?seminar_ID=6

Johnson, C., Shepley, J., Ferrante, J., and Sprong, K. (2009). *Atlantic Initiative to Reduce Emissions (AIRE) optimized profile descent operations at Atlanta: Analysis and results*. MP090145. McLean, VA: The MITRE Corporation.

Joseph, K. M., Domino, D., Battiste, V., Bone, R., and Olmos, B. O. (2003). *Summary of flightdeck observer data from SafeFlight 21 OpEval-2*. DOT/FAA/AM-03/2. Oklahoma City, OK: FAA CAMI.

Kopardekar, P., Green, S., Roherty, T., and Aston, J. (2003). *Miles-in-trail operations: A perspective.* Proceedings of the AIAA 3rd Annual Aviation Technology, Integration, and Operations (ATIO) Conference. Reston, VA: AIAA, Inc.

Lohr, G. W., Oseguera-Lohr, R. M., Abbott, T. S., Capron, W. R., and Howell, C. T. (2005). *Airborne evaluation and demonstration of a time-based airborne inter-arrival spacing tool*. NASA/TM-2005-213772. Hampton, VA: NASA Langley Research Center.

Melanson, D. (1973). *Simulator evaluation of pilot assurance derived from an airborne traffic situation display*. FAA-EM-74-10. Washington, DC: DOT FAA.

Mercer, J., Callatin, T. J., Lee, P. U., Prevot, T. and Palmer, E. (2005). *An evaluation of airborne spacing in the terminal area.* Proceedings of the 2005 IEEE/AIAA 24th Digital Avionics Systems Conference, Washington, DC, October 2005. Piscataway, NJ: IEEE Press.

Moertl, P. M. and Pollack, M. E. (2011). *Airline Based En Route Sequencing and Spacing field test results.* Proceedings of the Ninth USA/Europe Air Traffic Management Research and Development Seminar (ATM2011), Berlin, Germany, June 2011. Available at: http://www.atmseminar.org/papers.cfm?seminar_ID=9

Oseguera-Lohr, R. M., Lohr, G. W., Abbott, T. S. and Eischeid, T. M. (2002). *Evaluation of operational procedures for using a time-based airborne inter-arrival spacing tool – AIAA 2002-5824.* Proceedings of the AIAA's Aircraft Technology, Integration, and Operations (ATIO,) Los Angeles, California, October 2002. Reston, VA: AIAA, Inc.

Penhallegon, W. J. and Bone, R. S. (2009). *Flight Deck-Based Merging and Spacing during en route descent: Findings from an air traffic controller simulation.* Proceedings of the 8th USA / Europe Air Traffic Management R&D Seminar, Napa Valley, CA. Available at: http://www.atmseminar.org/8th-seminar-united-states-june-2009/papers

Penhallegon, W. J., Mendolia, A., Bone, R., Orrell, G., and Stassen, H.P. (2011). *Flight deck-based Interval Management – Spacing during departures: Flight crew Human-in-the-loop (HITL) simulation*. MTR110382. McLean, VA: The MITRE Corporation.

Peterson, Trevor, Penhallegon, W. J., and Moertl, P. (2012) *Mid-Term Interval Management-Spacing for Arrivals: Results from an En Route, Air Traffic Control Human-In-The-Loop Simulation.* MTR 120203. McLean, VA: The MITRE Corporation.

Ren, L., Clarke, J. P., and Ho, N. T. (2003). *Achieving low approach noise without sacrificing capacity.* Proceedings of the 2003 IEEE/AIAA 22nd Digital Avionics Systems Conference, Indianapolis, IN, October 2003. Piscataway, NJ: IEEE Press.

Rhodes, L. S., and Rhodes, L. R. (2001). *Operational characteristics and application of miles-in-trail restrictions*. MP01W0000109. McLean, VA: The MITRE Corporation.

RTCA (2015). *Safety, performance and interoperability requirements document for Airborne Spacing—Flight Deck Interval Management (ASPA-FIM)*. RTCA DO-328 Rev A. Washington, DC: RTCA.

RTCA and EUROCAE (2011). *Data Communications safety and performance requirements. Version I – Converged SPR, 18 November 2011. Section 5 Controller Pilot Data Link Communications (CPDLC) Application*. Available at www.faa.gov/go/SC214

Tong, K, Boyle, D. A., and Warren, A. W. (2006). *Development of continuous descent arrival procedures for dual-runway operations at Houston Intercontinental.* Proceedings of the 6th AIAA Aviation Technology, Integration and Operations Conference (ATIO), Wichita, Kansas, September 2006. Reston, VA: AIAA, Inc.

Weitz, Lesley A., Katkin, R., Moertl, P., Penhallegon, W. J., Hammer, J. B., Bone, R. S., and Peterson, T. (2012). *Considerations for Interval Management Operations in a Mixed-Equipage Environment.* Proceedings of the 12th American Institute of Aeronautics and Astronautics Aviation Technology, Integration, and Operations Conference (AIAA ATIO). Indianapolis, Indiana. September 2012

Weitz, L. A., Hurtado, J. E., Barmore, B. E., and Krishnamurthy, K. (2005). *An analysis of merging and spacing operations with continuous descent approaches.* Proceedings of the 2005 IEEE/AIAA 24th Digital Avionics Systems Conference, Washington, DC, Oct. 2005. Piscataway, NJ: IEEE Press.

Williams, D. H., and Wells, D. C. (1986). *Jet transport flight operations using cockpit display of traffic information during instrument meteorological conditions*. NASA Technical Paper 2567. Hampton, VA: NASA Langley.

Appendix A Flight Deck Observer Form and Pilot Questionnaire

The flight deck observer form was used by each of the observers to record notes and observations during the flight. The pilot questionnaires were given to each of the pilots to fill out and return to the observers post-flight.

FIM 2010 Field Data Collection Flight Deck Observer Form		
Observer Name:	**Arrival Path (e.g., Brown; Cheri):**	**Departure Date:**
Flight ID: UPS____	**Wheels-Up Time (GMT):**	**Departure Gateway:**

RANGE to Target Aircraft			
Ownship at Merge: _____	**Ownship at TOD: ______**	**Ownship at FAF: ______**	**TGT at Threshold: _____**

FIM Initiation	**1. Please record the following about the target aircraft assignment:**					
	a. Time Received	b. Target Assignment	c. Assigned Interval	d. Merge Fix		
	2. Did crew have any difficulty locating the target aircraft on the CDTI?				Yes	No
	Notes (ask crew for preference/thoughts about selecting target: graphical vs. typing in ID):					
	3. Did crew have any difficulties using the CDTI to set up for FIM?				Yes	No
	Notes:					
	4. Other FIM Initiation observations:					
	Notes:					

Event Time (GMT) [________]	**Domain** *(please circle)*				
	Pre-Merge	Post-Merge	Terminal		
☐ **CMD Magnitude** [_________] mach / kts	Pilot Response Value(s): ________	Was CMD: ___Delayed? (___sec)	___Ignored?	___Missed?	RNG to TGT
☐ **Comms with ATC** *Facility:* ___	Notes (including transcripts with ATC and any use of third party call sign):				
"Company Spacing" on CI? *Circle:* Y / N					
☐ **Crew Comment / Action** *Circle:* CPT / FO					
☐ **CDTI Interaction** *Circle:* CPT / FO					
☐ **Equipment Problem**					

Event Time (GMT) [________]	**Domain** *(please circle)*					
	Pre-Merge		Post-Merge		Terminal	
CMD Magnitude [________] mach / kts	Pilot Response Value(s): ________	Was CMD: ___Delayed? (___sec)	___Ignored?	___Missed?	RNG to TGT	
Comms with ATC *Facility:* ___	Notes (including transcripts with ATC and any use of third party call sign):					
"Company Spacing" on CI? *Circle:* Y / N						
Crew Comment / Action *Circle:* CPT / FO						
CDTI Interaction *Circle:* CPT / FO						
Equipment Problem						

Event Time (GMT) [________]	**Domain** *(please circle)*					
	Pre-Merge		Post-Merge		Terminal	
CMD Magnitude [________] mach / kts	Pilot Response Value(s): ________	Was CMD: ___Delayed? (___sec)	___Ignored?	___Missed?	RNG to TGT	
Comms with ATC *Facility:* ___	Notes (including transcripts with ATC and any use of third party call sign):					
"Company Spacing" on CI? *Circle:* Y / N						
Crew Comment / Action *Circle:* CPT / FO						
CDTI Interaction *Circle:* CPT / FO						
Equipment Problem						

Note: pages 2 – 14 of the full observer form were the same.

Interventions and Surface Map Questions

Interventions: Ownship	1. Did ATC make any interventions with <u>YOU</u> *after* the spacing operation started?			Yes	No
	a. If yes, when?		Pre-merge	Post-merge	Terminal
	b. If yes, who?	Z___	ZKC	ZID	TRACON
	c. If yes, what? (if other, describe below)		heading	speed	other
	d. If yes, did it result in FIM termination for you?			Yes	No
	Time of intervention(s): ___________ Notes:				
Interventions: TGT	2. Did ATC make any interventions with your <u>TGT aircraft</u> that you noticed *after* the spacing operation started?			Yes	No
	a. If yes, when?		Pre-merge	Post-merge	Terminal
	b. If yes, who?	Z___	ZKC	ZID	TRACON
	c. If yes, what? (if other, describe below)		heading	speed	other
	d. If yes, did it result in FIM termination for you?			Yes	No
	Time of intervention(s): ___________ Notes:				
Surface Map	7. Was the <u>SURFACE MAP</u> used?			Yes	No
	What time/location did the pilot start using it? **departure taxi / short final / rollout / exit runway / taxi to gate / Other?** ___________ Notes:				
	8. If possible, during final approach, look on CDTI for closest aircraft ahead of you on the parallel approach (if any). As best you can, watch this aircraft during your roll-out and taxi. Does this aircraft ever disappear from the display shortly after landing?			Yes	No
	If so, please note, ACID: __________ Time of disappearance: _____________				

Interview Questions to Ask Pilots as Time Permits

1) How long has it been since you received specific training for this spacing operation?
   Captain:

   FO:

2) What was the form of your most recent training (briefing, computer-based, checkride, etc.)?
   Captain:

   FO:

3) How many times have you previously done this spacing operation?
   Captain:

   FO:

4) (Post-flight) Is there any additional information that you would have liked to have had to make your task easier?
   Captain:

   FO:

Flight deck-based Interval Management
2010 Field Test Pilot Questionnaire

Flight ID: UPS_____ Departure Date: _______ Departing Gateway: ______

Please circle your roles on this flight: **Pilot Flying** **Pilot Not Flying** **Captain** **FO**

Instructions: Please circle YES or NO for the following questions based on tonight's flight.

1. For the speed commands you received via the AGD/CDTI displays:			
1a. Was the *number* of speed commands you received *acceptable*?	Yes	No	
1b. Were any of the speed commands *unacceptable*?	Yes	No	If **No**, goto 2
1c. If yes, please describe the unacceptable speed commands:			

2. Was your *overall workload acceptable* while conducting the spacing operation?		Yes	No
2a. Did the spacing operation *increase or decrease your workload*?	Inc	Same	Dec
3. Was your overall *head down time* acceptable while conducting the spacing operation?		Yes	No
3a. Did the spacing operation *increase or decrease your head down time*?	Inc	Same	Dec
4. Were you unsure at any point that the equipment was providing appropriate speed commands?		Yes	No
4a. Were you confident overall that the equipment was giving you appropriate speed commands?		Yes	No
5. Beyond setup, was the graphical CDTI required to perform the spacing operation?		Yes	No
6. Was the alerting for new speed commands acceptable for getting your attention?		Yes	No
7. Were the spacing operation procedures (e.g., initiation, conduct, and termination) clear?		Yes	No
8. Were you able to effectively coordinate spacing tasks with the other pilot?		Yes	No
9. Did you have any problems communicating with ATC about the spacing operation?		Yes	No
10. Was the spacing operation compatible with normal flight deck operations?		Yes	No
11. Would you have any objection to flying the spacing operation on a routine basis?		Yes	No

12. Please provide any comments based on your replies to the above questions. Feel free to use the back if you run out of room:

____

____

____

13. Would it be ok for us to contact you if we have any follow-up questions? If so, please provide your information for how you would like to be reached:

Name: ____________________ Phone: ______________ E-mail: ____________________________

Thank-you for your participation!

Appendix B ATC Observer Forms (ZKC, ZID, Louisville TRACON)

Note: The following forms were not given to controllers to fill out. The ATC observers used them as a guide for what to look for while at the facilities. Time permitting, the observers asked the controllers some of the questions in these forms and made note of the answers.

Date: __________

ZKC FIM Observation Form

Observation **start** time (GMT) ________ Observer Name ___________________

Observation **stop** time (GMT) ________ Use other side/blank space for details – refer with question number

Departure Gateway	Trail	→	Lead
PHX	UPS857	→	
LAX	UPS903	→	
LGB	UPS905	→	
ONT	UPS919	→	
SAN	UPS921	→	

Describe facility preparations for this exercise:

1. Describe observation setting (Do you have audio? At own console? Standing behind controller? Following flights as they progressed through center? Etc.)

2. Describe the observed positions (which sectors you are watching, progress through sectors)

3. Describe sector configuration (combined sectors: merge / high / low …)

4. Describe wind/weather conditions (winds aloft – wx report, if possible, from TMU; convective activity; any other special weather conditions)

5. Was sector configuration R-side / D-side / other?

6. Describe traffic flow (qualitatively, plot sector boundaries, streams, and merge points)

7. Describe any traffic flow modifications (e.g. reroutes, deviations, non-FIM aircraft filling gaps between FIM aircraft, etc.)

8. Did the controller accept or clear direct routings? If so, please note flights numbers and new routing.

9. Describe any other special conditions (traffic flow management constraints, etc.)?

10. How did the controllers in this center refer to FIM? (e.g. “FDMS”, “self-spacing”, etc.)

11. Describe any additional pre-coordination with UPS. Did any issues/concerns arise from it?

12. Estimate the amount of traffic in each area during FIM operations and if the controller(s) seemed busy.

Date: __________

Observation questions for sector(s) where FIM is occurring:

13. Were FIM aircraft merging in ZKC? If so, were they merging with appropriate spacing or did the controller need to intervene to ensure separation at the merge fix?

14. What was the controller's spacing goal for SDF arrivals? (running 5 MIT? 6? Other?) Was it different for FIM aircraft?

15. Did the controller(s) vector any of the FIM flights after FIM had started? If so, why?

16. Did the controller ever initiate a speed adjustment to the FIM flights after FIM had started? If so, why?

17. Did you observe a case where a FIM flight crew requested a speed change from ATC? If so, did the controller accept or not accept those speed requests by the flight crew?

18. Did the controller delay providing vector or speed changes due to FIM operations that he may have otherwise given? (e.g. comments during the observation, post-interview)

19. Was there any issue with flights changing speeds for FIM?

20. Did the controller actively adjust the sequence of FIM flights?

21. For each area, please describe level of frequency congestion during FIM operations (e.g. sparse transmissions; moderate loading; busy with frequent transmissions).

22. Were there any issues/concerns with aircraft announcing that they were conducting company spacing?

23. Were there any irregular pilot-controller comms or any misunderstandings?

24. Did you observe any problems / issues during your observation period (e.g. including communications) concerning FIM?

25. Was there a situation in which the controller terminated FIM? If so, why?

26. Did the controller(s) appear to treat FIM aircraft differently than non-FIM aircraft?

27. Were there any problems with other arrivals or surrounding traffic disrupting the FIM operations?

Date: __________

"Company Spacing" on check-in (Y/N)

(Please write yes or no to indicate whether AC announced "company spacing" when checking in.)

Area (please note)	UPS857 (PHX)	UPS903 (LAX)	UPS905 (LGB)	UPS919 (ONT)	UPS921 (SAN)
1.					
2.					
3.					
4.					

Observation questions for post-interview (if possible)

1. Did you know about FIM operations? If so, what was your knowledge about FIM?
2. What effect did FIM/CDA operations have on your workload?
3. Were non-FIM arrivals adversely affected by FIM?
4. Would you be or were you comfortable inserting an aircraft between a pair of aircraft already conducting FIM?
5. What effect did FIM/CDA operations have on communications?
6. Did you find it acceptable to be responsible for separation during FIM operations?
7. Was there any information concerning CDA/FIM that you would have wanted to have but did not have?
8. Do you have any other comments about what you saw tonight?

Date: ___________

ZID FIM Observation Form

Observation **start** time (GMT) ________ Observer Name ___________________

Observation **stop** time (GMT) ________ Use other side/blank space for details – refer with question number

Departure Gateway	Trail	→	Lead
PHX	UPS857	→	
LAX	UPS903	→	
LGB	UPS905	→	
ONT	UPS919	→	
SAN	UPS921	→	

Describe facility preparations for this exercise:

1. Describe observation setting (Do you have audio? At own console? Standing behind controller? Following flights as they progressed through center? Etc.)

2. Describe the observed positions (which sectors you are watching, progress through sectors)

3. Describe sector configuration (combined sectors: merge / high / low …)

4. Describe wind/weather conditions (winds aloft – wx report, if possible, from TMU; convective activity; any other special conditions)

5. Was sector configuration R-side / D-side / other?

6. Describe traffic flow (qualitatively, plot sector boundaries, streams, and merge points)

7. Describe any traffic flow modifications (e.g. reroutes, deviations, non-FIM aircraft filling gaps between FIM aircraft, etc.)

8. Did the controller accept or clear direct routings? If so, please note flights numbers and new routing.

9. Describe any special conditions (traffic flow management constraints, etc.)?

10. How did the controllers in this center refer to FIM? (e.g. “FDMS”, “self-spacing”, etc.)

11. Describe any additional pre-coordination with UPS and/or ZKC. Did any issues/concerns arise from it?

12. Estimate the amount of traffic and if the controller seemed busy.

Date: __________

Observation questions for sector(s) where FIM is occurring:

13. Were FIM aircraft merging in ZID? If so, were they merging with appropriate spacing or did the controller need to intervene to ensure separation at the merge fix? Did spacing improve or degrade over time?

14. What was the controller's spacing goal for SDF arrivals? (running 5 MIT? 6? Other?) Was it different for FIM aircraft?

15. Did the controller(s) vector any of the FIM flights? If so, why?

16. Did the controller ever initiate a speed adjustment to the FIM flights? If so, why?

17. Did you observe a case where a FIM flight crew requested a speed change from ATC? If so, did the controller accept or not accept those speed requests by the flight crew?

18. Did the controller delay providing vector or speed changes due to FIM operations that he may have otherwise given? (e.g. comments during the observation, or post-interview)?

19. Was there any issue with flights changing speeds for FIM?

20. Did the controller actively adjust the sequence of FIM flights?

21. Please describe level of frequency congestion during FIM operations (e.g. sparse transmissions; moderate loading; busy with frequent transmissions).

22. Were there any issues/concerns with aircraft announcing that they were conducting company spacing?

23. Were there any irregular pilot-controller comms or any misunderstandings?

24. Did you observe any problems / issues during your observation period concerning FIM?

25. Was there a situation in which the controller(s) terminated FIM? If so, why?

26. Did the controller(s) appear to treat FIM aircraft differently than non-FIM aircraft?

27. Were there any problems with other arrivals or surrounding traffic disrupting the FIM operations?

Date: __________

“Company Spacing” on check-in (Y/N)

(Please write yes or no to indicate whether AC announced “company spacing” when checking in.)

Area	UPS857 (PHX)	UPS903 (LAX)	UPS905 (LGB)	UPS919 (ONT)	UPS921 (SAN)
1.					
2.					

Observation questions for post-interview (if possible)

1. Did you know about FIM operations? If so, what was your knowledge about FIM?
2. What effect did FIM/CDA operations have on your workload?
3. Were non-CDA arrivals adversely affected by the CDAs/FIM?
4. Would you be or were you comfortable inserting an aircraft between a pair of aircraft already conducting FIM?
5. What effect did FIM/CDA operations have on communications?
6. Did you observe issues with FIM aircraft have varying TOD points? (e.g. additional radio communications)?
7. Did you find it acceptable to be responsible for separation during FIM operations?
8. Was there any information concerning CDA/FIM that you would have wanted to have but did not have?
9. Do you have any other comments about what you saw tonight?

Date: ___________

Louisville TRACON FIM Observation Form

Observation **start** time (GMT) ________ Observer Name ___________________

Observation **stop** time (GMT) ________ Use other side/blank space for details – refer with question number

Departure Gateway	Trail	→	Lead
PHX	UPS857	→	
LAX	UPS903	→	
LGB	UPS905	→	
ONT	UPS919	→	
SAN	UPS921	→	

Describe facility preparations for this exercise:

1. Describe observation setting (Do you have audio? At own console? Standing behind controller? Etc.)

2. Describe terminal area configuration.

3. Describe wind/weather conditions during descent and on the surface (wx report, including convective activity; any other special conditions)

4. Describe traffic flow (qualitatively, streams, and merge points)

5. Describe any traffic flow modifications (e.g. reroutes, deviations, non-FIM aircraft filling gaps between FIM aircraft, etc.)

6. Describe any other special conditions (traffic flow management constraints, etc.)?

7. How did the controller(s) refer to FIM? (e.g. "FDMS", "self-spacing", etc.)

8. Describe any additional pre-coordination with ZID and/or UPS. Did any issues/concerns arise from it?

9. Estimate the amount of traffic and if the controller seemed busy.

"Company Spacing" on check-in (Y/N)

(Please write yes or no to indicate whether AC announced "company spacing" when checking in.)

UPS857 (PHX)	UPS903 (LAX)	UPS905 (LGB)	UPS919 (ONT)	UPS921 (SAN)

Date: __________

Observation questions for FIM operation:

10. Were FIM arrivals properly spaced when they entered the terminal area? How good was the initial spacing? Did it improve or degrade over time?

11. Did the controller(s) vector any of the FIM flights? If so, why?

12. Did the controller ever initiate a speed adjustment to the FIM flights? If so, why?

13. Did you observe a case where a FIM flight crew requested a speed change from ATC? If so, did the controller accept or not accept speed requests by the flight crew?

14. Did the controller delay providing vector or speed changes due to FIM operations that he may have otherwise given? (e.g. comments during the observation, or post-interview)?

15. Was there any issue with flights changing speeds for FIM?

16. Did the controller actively adjust the sequence of FIM flights?

17. Please describe level of frequency congestion during FIM operations (e.g. sparse transmissions; moderate loading; busy with frequent transmissions).

18. Were there any issues/concerns with aircraft announcing that they were conducting company spacing?

19. Were there any irregular pilot-controller comms or any misunderstandings?

20. Did you observe any problems / issues during your observation period concerning FIM?

21. Was there a situation in which the controller(s) terminated FIM? If so, why?

22. Did the controller(s) appear to treat FIM aircraft differently than non-FIM aircraft?

23. Did controller seem to monitor flights at increased levels during the CDA compared to conventional operations? (discuss with Wes)

24. Were there any problems with other arrivals or surrounding traffic disrupting the FIM operations?

25. Do the aircraft follow uninterrupted CDAs/FIM?

Date: __________

<u>Observation questions for post-interview</u> (if possible)

1. Did you know about FIM operations? If so, what was your knowledge about FIM?

2. What effect do FIM/CDA operations have on your workload?

3. Would you be or were you comfortable inserting an aircraft between a pair of aircraft already conducting FIM?

4. Were non-CDA arrivals adversely affected by the CDAs/FIM?

5. Was there a noticeable impact of aircraft conducting FIM on ATC communications, as compared to controlling a similar number of aircraft without FIM?

6. Did you find it acceptable to be responsible for separation during FIM operations?

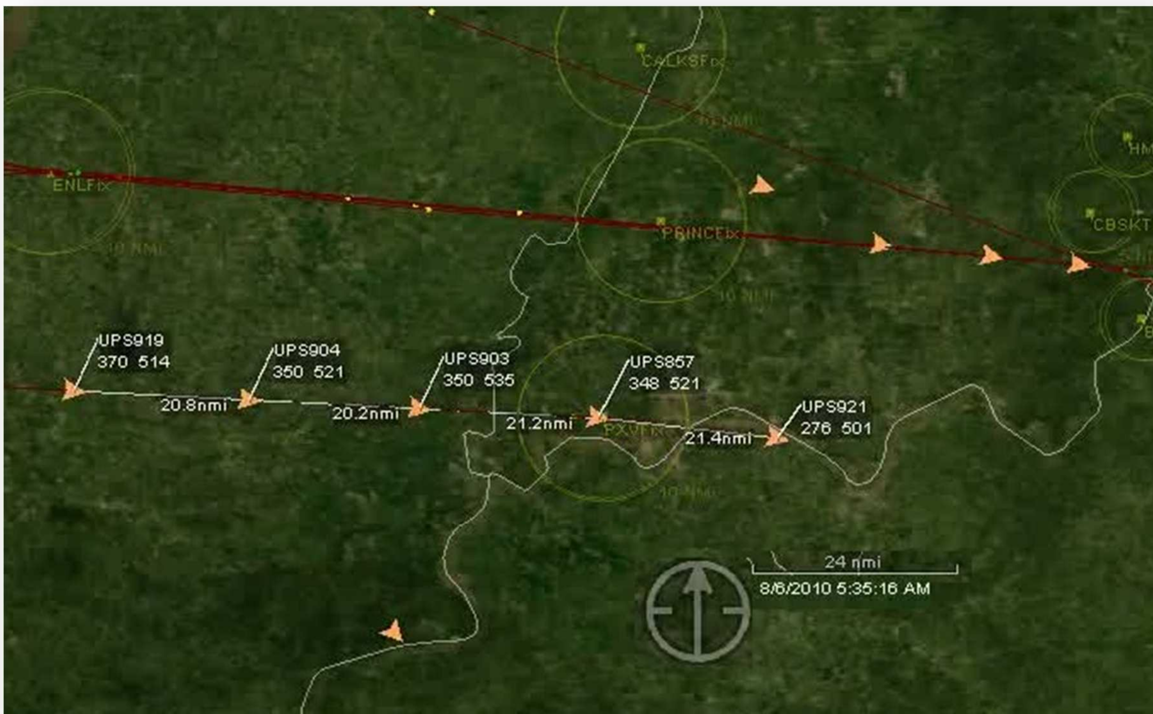
7. Was there any information concerning CDA/FIM that you would have wanted to have but did not have?

8. Do you have any other comments about what you saw tonight?

Appendix C Flight Progression Snapshots

The following figures show the progression of the IM-S AA test sequence for each of the test nights. Data blocks that include call sign, altitude, and groundspeed are presented for each aircraft. The straight-line distance between each aircraft pair is represented by connector lines and a range readout in NM. The visualizations in this section were captured and adjusted by MITRE from animations created by JHU APL.

C.1 Night 1 Sequence



JHU APL

Figure C-1. Night 1 UPS857 at PXV (05:35:16 UTC)

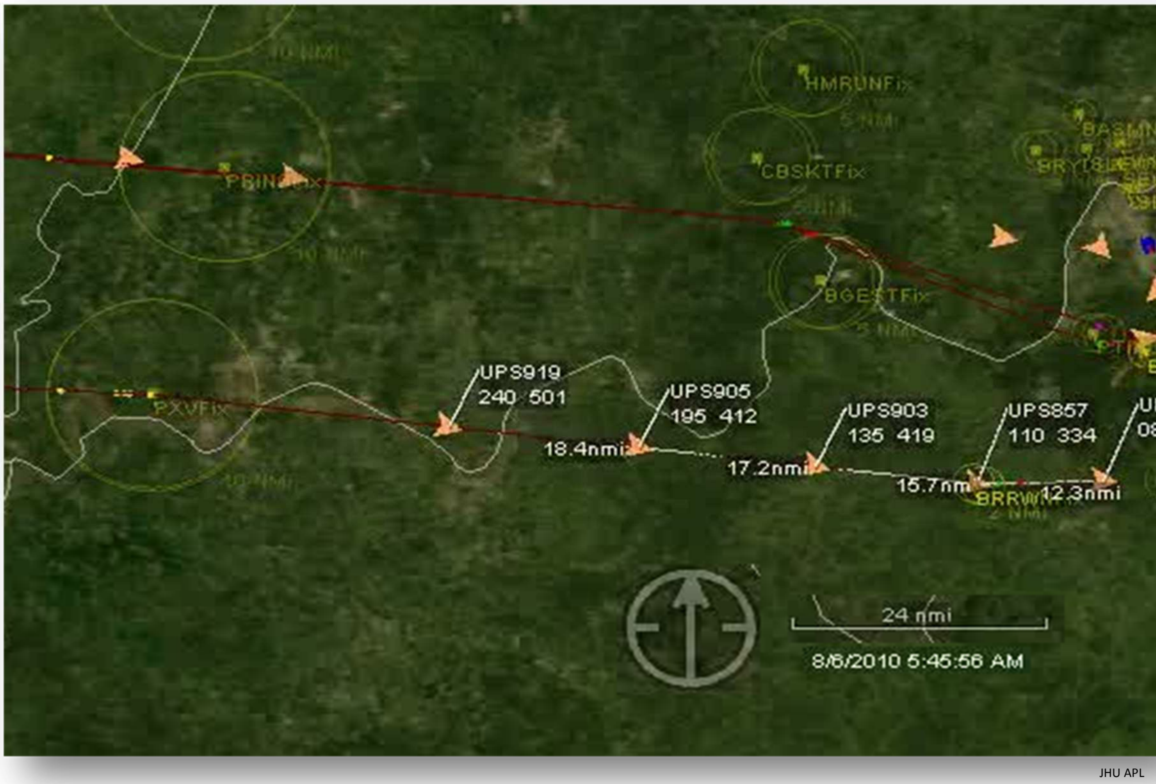


Figure C-2. Night 1 UPS857 at BRRWN (05:45:56 UTC)

Figure C-3. Night 1 UPS857 at JMCSY (05:49:36 UTC)

JHU APL

Figure C-4. Night 1 UPS857 at BRNBX (05:51:36 UTC)

JHU APL

Figure C-5. Night 1 UPS857 at UPSCO (05:53:00 UTC)

JHU APL

Figure C-6. Night 1 UPS857 at SAFLT (05:53:28 UTC)

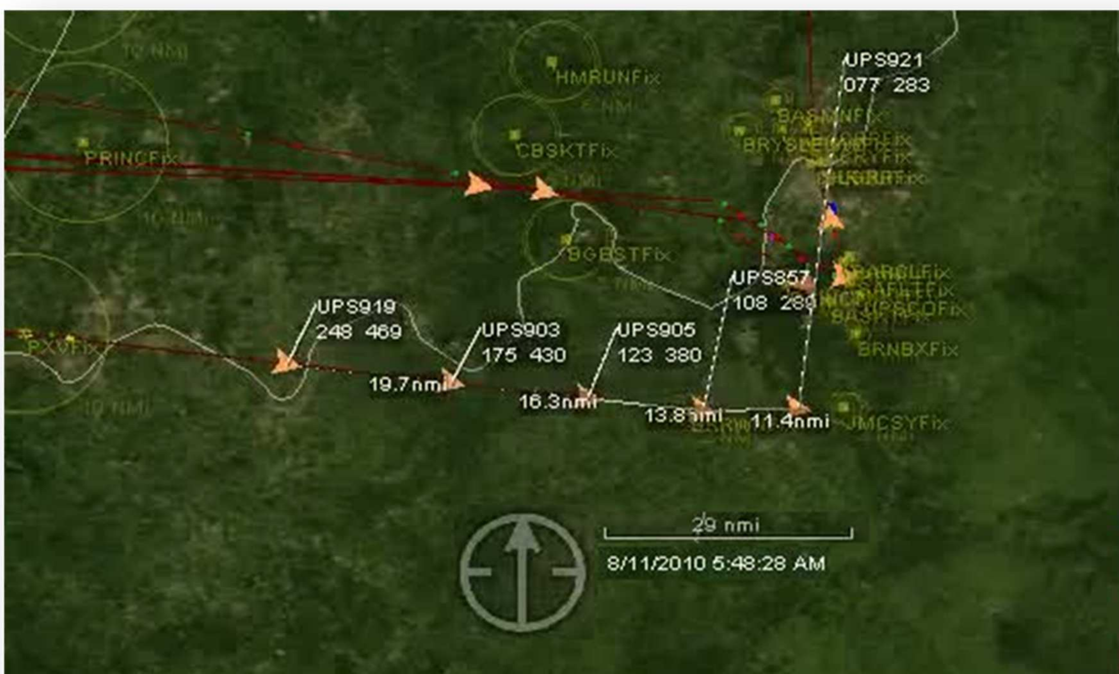
JHU APL

Figure C-7. Night 1 UPS857 at PARCL (05:54:20 UTC)

C.2 Night 2 Sequence

JHU APL

Figure C-8. Night 2 UPS857 at PXV (05:37:04 UTC)



JHU APL

Figure C-9. Night 2 UPS857 at BRRWN (05:48:28 UTC)

Figure C-10. Night 2 UPS857 at JMCSY (05:52:02 UTC)

Figure C-11. Night 2 UPS857 at BRNBX (05:54:00 UTC)

Figure C-12. Night 2 UPS857 at UPSCO (05:55:04 UTC)

Figure C-13. Night 2 UPS857 at SAFLT (05:55:48 UTC)

Figure C-14. Night 2 UPS857 at PARCL (05:56:28 UTC)

C.3 Night 3 Sequence

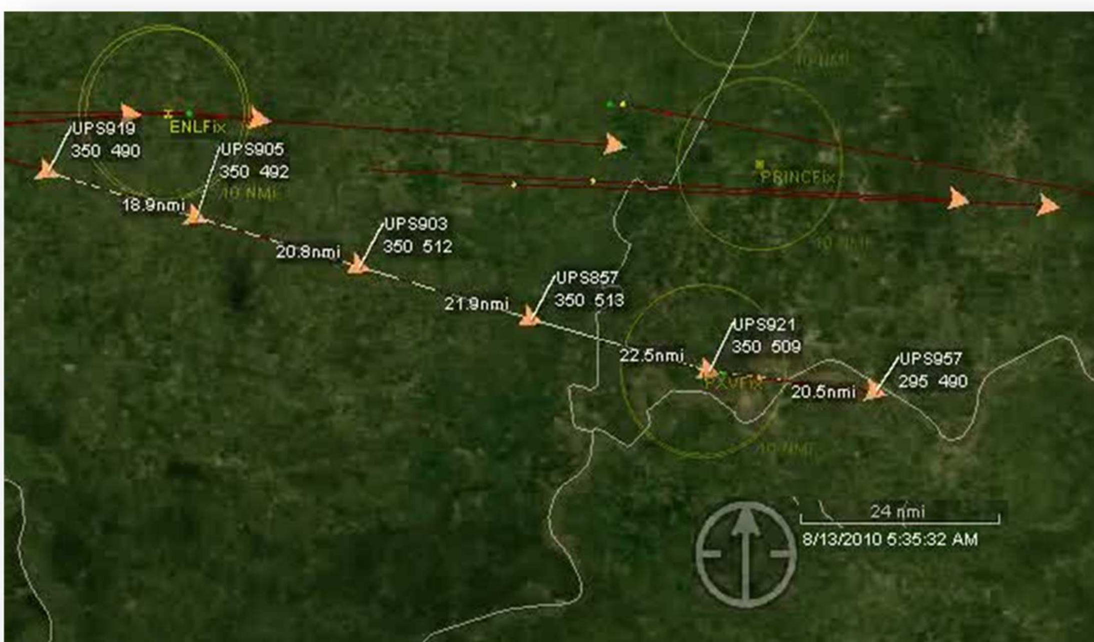


Figure C-15. Night 3 UPS921 at PXV (05:35:32 UTC)

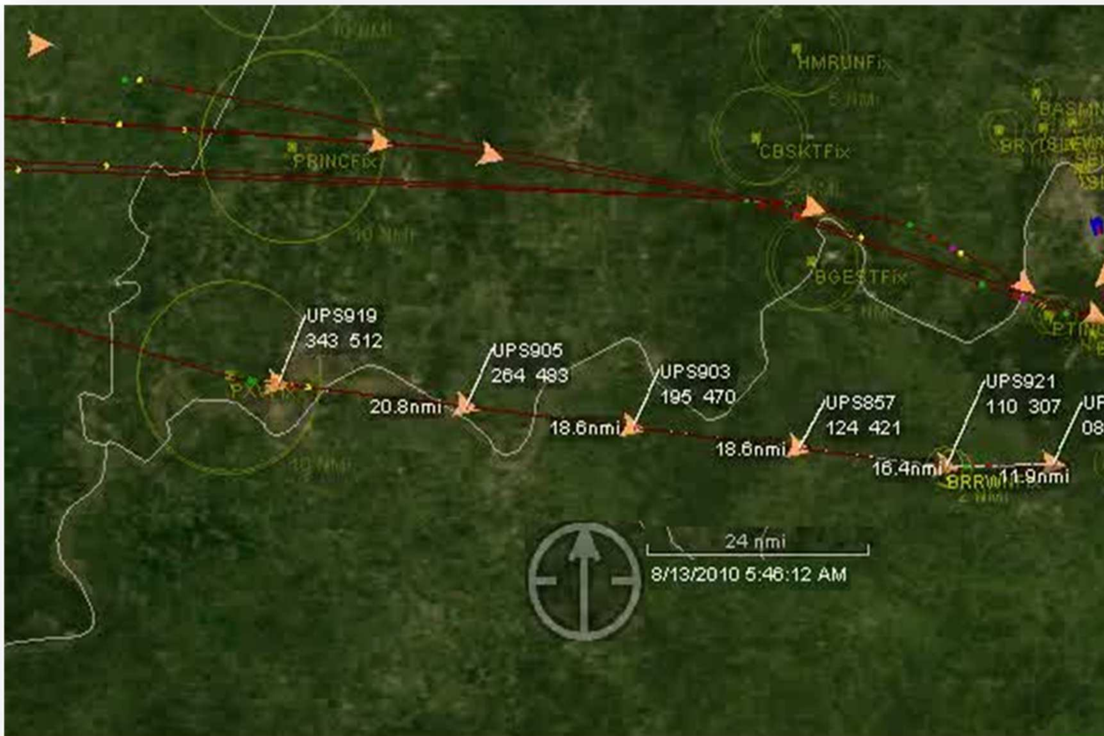


Figure C-16. Night 3 UPS921 at BRRWN (05:46:12 UTC)

Figure C-17. Night 3 UPS921 at JMCSY (05:50:07 UTC)

Figure C-18. Night 3 UPS921 at BRNBX (05:52:00 UTC)

Figure C-19. Night 3 UPS921 at UPSCO (05:53:12 UTC)

JHU APL

Figure C-20. Night 3 UPS921 at SAFLT (05:53:48 UTC)

JHU APL

Figure C-21. Night 3 UPS921 at PARCL (05:54:31 UTC)

Appendix D IM-S AA Flight Progression Timelines

The timelines in this section were compiled from several data sources and form the basis for most of the analyses in Section 4. The flight deck observational data was recorded by NASA Ames and MITRE. SafeRoute and other data provided by ACSS and JHU APL. The data sources for specific data elements are provided in Table D-1. The timelines were compiled and summarized by MITRE.

Table D-1. Timeline Data Element Sources

Data Element	Source(s)
Wheels up	UPS
IM-S AA instruction received	Flight Deck Observer
Start IM-S AA	SafeRoute On-Board Data Collection / Estimated Based on 300 NM Along-Track Distance from PXV
IM Speed value / Crew SPD values	SafeRoute On-Board Data Collection / Flight Deck Observer
Pilot SEL Input	SafeRoute On-Board Data Collection / Flight Deck Observer
ATC change	Flight Deck Observer
Fix Crossings	Flight Deck Observer / JHU APL
Pilot SEL Input	SafeRoute On-Board Data Collection / Flight Deck Observer
Speed Input Response Notes	SafeRoute On-Board Data Collection / Flight Deck Observer
Ownship Speed, Altitude, Time Spacing	SafeRoute On-Board Data Collection
TGT TD, RNG to TGT	SafeRoute On-Board Data Collection / Flight Deck Observer / JHU APL
Notes	Flight Deck Observer / Pilot Questionnaires

Operationally, IM-S AA is intended to begin formally no closer than 300 NM from the achieve-by point (PXV). During the setup phase, many crews input reference aircraft and SIs and aircraft manually maneuvered into in-trail positions at far greater ranges. However, to provide a common point of comparison, the formal start of IM-S AA operations is considered to be 300 NM (west) along track distance range from PXV. Most IM and crew-initiated speed changes outside the 300 NM range are included in the tables; however, the analyses include only IM-S AA IM Speeds inside this range.

Many observers did not note the precise time that their aircraft entered the terminal area (i.e., checked in on the terminal communications frequency). In these events, the BRRWN fix crossing is assumed to be the terminal area entry; the aircraft's actual entry is likely to be +/- 5 minutes of this time. Assumed terminal area entry points are noted in the timelines.

When SafeRoute data was available, most events were captured with 1-second precision. However, when only observer data was available, events were estimated to the nearest minute.

D.1 Night 1 Flight Deck Timelines

Table D-2. UPS857 Night 1 Flight Deck Timeline

UPS919 → UPS905 → UPS903 → **UPS857** → UPS921

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
03:03	Departure	Wheels up								
03:34										• Captain commented that the tool was really handy for tracking. • Captain reported that the spacing tools and CDTI keeps them engaged. • FO reported that the tools also help to raise situation awareness
04:31		ATC request								• ATC inquired if ownship could go higher for traffic avoidance. • Ownship confirm that it could, but informed ATC that they were company spacing. • ATC instructed ownship to disregard request
04:35	Pre-IM-S AA	IM-S AA instruction received		0.83		0.83 / 284	35013	168	24.7	Note: crew input SI = 150 sec
04:35:25		IM Speed	0.80	0.80	144	0.83/ 284	35013	168	24.7	
04:39:01		Crew SPD		0.79		0.80/ 273	34999	175	23.4	
04:40:27		IM Speed	0.76	0.76	17	0.79/ 269	35004	167	22.9	
04:46:25		Crew SPD		0.75		0.78/ 264	35007	162	22.6	
04:48:49		Crew SPD		0.74		0.75/ 253	35010	165	22.4	
04:53:32		IM Speed	0.74	-	Already Selected	0.75/ 253	35012	161	22.1	

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
04:59:18	Achieve	Start IM-S AA				0.74/ 249	35007	159	21.5	Ownship 300 NM from PXV
05:21:27		Crew SPD		0.80		0.75/ 252	35008	153	20.6	Lead announces it will fly 0.8 mach
05:24:23		Crew SPD		0.78		0.80/ 273	35003	142	20.6	
05:24:32		IM Speed	0.79	0.79	305	0.80/ 273	35001	142	20.6	
05:34:57		TOD						149	21.3	
05:35:16	Maintain	PXV						149	21.2	
05:35:19		IM Speed	0.82	0.82	37	0.79/ 269	34644	149	21.2	
05:36:05	Initial Descent	IM Speed	300	300	10	0.81/ 293	32297	150	20.8	
05:38:47		IM Speed	315	315	14	0.71/ 299	24749	149	19.4	
05:44:19	BRRWN Restriction	Crew SPD		240		0.59/ 315	12148	152	14.2	
05:44:34		IM Speed	265	-	-	0.58/ 312	11729	152	13.7	Not selected since SEL was already set at 240
05:45:40	Arrival Turn	BRRWN				0.49/ 267	11125	150	12.5	Assumed terminal entry time
05:45:53		IM Speed	250	-	-	0.47/ 258	10995	149	12.4	Not selected since SEL was already set at 240
05:48:50		IM Speed	235	-	-	0.42/ 243	7456	145	9.3	
05:49:23		JMCSY				0.40/ 235	6865	145	10.2	
05:50:48		Crew SPD		230		0.40/ 238	5421	145	9.6	
05:51:40	Final Descent	BRNBX				0.38/ 231	4513	146	8.5	
05:52:04		Crew SPD		210		0.38/ 233	4000	146	7.9	
05:52:05		IM Speed	200	-	-	0.38/ 232	3980	146	7.9	

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:52:56		UPSCO				0.34/ 210	3510	145	6.6	
05:53:12		IM Speed	169	-	-	0.34/ 212	3258	144	6.2	
05:53:16		Crew SPD		190		0.34/ 210	3219	144	6.1	
05:53:48		Crew SPD		153		0.30/ 187	3048	142	5.5	
05:54:16		PARCL				0.27/ 168	2653	142	5.3	
05:54:19		Crew SPD		139		0.27/ 169	2555	142	5.3	
05:54:26		IM Speed	168	-	-	0.26/ 166	2393	141	5.2	
05:54:40	Post IM-S AA	TGT TD					2150	139	5.1	Target touchdown
05:54:48		1500 AGL					1998			Ownship crosses 1500 ft. AGL
05:56:33		TD								Ownship touchdown

Table D-3. UPS903 Night 1 Flight Deck Timeline

UPS919 → UPS905 → **UPS903** → UPS857 → UPS921

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
02:31	Departure	Wheels up								
04:18:20	Pre-IM-S AA	IM Speed	0.84	0.84	82	0.82/ 278	35009	276	42.4	
04:35		IM-S AA instruction received								
04:46:55		Crew SPD		0.82		0.84/ 288	34988	237	32.9	Lead aircraft slowed to .74. Crew: “We will accordion” but thought slowdown to 0.76 would be too drastic.
04:59:08		Crew SPD		0.81		0.82/ 280	35006	180	24.3	
05:01:00	Achieve	Start IM-S AA				0.81/ 276	35009	170	23.0	Ownship 300 NM from PXV (estimated)
05:04:05		IM Speed	0.81	-	Already Selected	0.81/ 276	35011	155	21.1	Not selected since SEL was already set at M0.81
05:05:28		IM Speed	0.76	0.76	7	0.81/ 274	35005	148	20.4	Crews coordinating that they will go to .80 when all a/c are in position
05:12:51		IM Speed	0.72	0.72	5	0.77/ 262	35010	140	19.1	
05:21:01		Crew SPD		0.79		0.73/ 245	35005	146	20.0	
05:22:46		Crew SPD		0.78		0.79/ 268	35018	144	20.1	
05:24:13		IM Speed	0.77	0.77	7	0.78/ 265	34996	140	20.4	
05:31:17		Crew SPD		0.79		0.78/ 264	35014	147	21.0	
05:31:31		IM Speed	0.80	0.80	3	0.78/ 263	35016	147	21.1	
05:37:13	Maintain / Initial Descent	PXV / TOD						144	20.6	
05:38:30		IM Speed	285	285	6	0.80/ 300	30594	144	19.8	

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:38:45		IM Speed	305	305	9	0.80/ 307	29632	144	19.6	
05:43:31		IM Speed	320	320	7	0.65/ 307	18345	148	17.2	
05:46:42	BRRWN Restriction	IM Speed	270	270	4	0.58/ 316	11159	148	13.7	
05:48:07		IM Speed	250	250	9	0.49/ 266	10999	146	12.3	
05:48:16	Arrival Turn	BRRWN				0.49/ 266	10777	146	12.1	
05:50:36		IM Speed	235	235	4	0.43/ 252	7537	143	8.8	
05:51:32	Terminal	IM Speed	220	220	6	0.40/ 237	6530	142	10.1	
05:51:52		JMCSY				0.39/ 230	6207	142	10.1	
05:52:17		IM Speed	235	-	-	0.37/ 220	5933	143	10	Not selected since SEL was already set at 220 Flaps out; no speed-up
05:54:07	Final Descent	BRNBX				0.36/ 222	4095	150	8.4	
05:54:19		IM Speed	220	-	Already Selected	0.36/ 220	3861	150	8.1	Not selected since SEL was already set at 220
05:55:11		IM Speed	171	-	-	0.35/ 220	3366	150	6.8	
05:55:24		UPSCO				0.35/ 219	3240	149	6.5	
05:55:41		Crew SPD		175		0.34/ 216	3072	148	6.1	
05:56:16		IM Speed	170	170	2	0.32/ 205	2463	140	5.4	
05:56:25	Post IM-S AA	TGT TD				0.31/ 198	2299	138	5.2	Target touchdown
05:56:34		Crew SPD		155		0.31/ 196	2140			
05:56:40		PARCL				0.30/ 190	2024			
05:56:41		1500 AGL				0.30/ 189	2004			Ownship crosses 1500 ft. AGL
05:56:53		Crew SPD		140		0.28/ 177	1809			
05:58:45		TD								Ownship touchdown

Table D-4. UPS905 Night 1 Flight Deck Timeline

UPS919 → **UPS905** → UPS903 → UPS857 → UPS921

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	Speed Input Response Notes	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
02:40	Departure	Wheels up								
03:22		IM-S AA instruction received								
03:55										CPT announces 145 sec, PXV merge, and following 140 kts on final approach
03:58:38		IM Speed	290	288		0.84/ 288	35043	324	37.8	Crew completes entering data into CDTI. IM Speed disappeared quickly and no further IM Speeds issued. Reason unknown.
04:00										CPT notes ahead aircraft turning to go around wx. Comment: found CDTI vector lines helpful to identify lead a/c turns
04:05:45		Crew SPD		286		0.85/ 289	35044			
04:06		HDG change								ATC: vector for traffic: 045 left turn
04:08:39		Crew SPD		287		0.83/ 284	35038			
04:19										CPT notes 903 is 38 miles in front of us; 919 is 15 miles behind us but ground speed is 6 kts faster—it is all wind
04:22:52		Crew SPD		0.84		0.80/ 272	34961			
04:30:04		Crew SPD		287		0.83/ 284	35054			

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	Speed Input Response Notes	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
04:41:05		Crew SPD		289		0.83/ 285	35047			
05:07										CPT notes voice plan is to go to 0.80 once 905 and 919 are in position.
05:21:28		Crew SPD		0.80		0.84/ 288	35034			
05:39		TOD								
05:40:02		PXV				0.80/ 277	34014			Due to lack of IM Speeds, crews managing to achieve 10 mi spacing (final)
05:41:08		Crew SPD		300		0.79/ 296	30629			
05:44:00		Crew SPD		280		0.69/ 295	23847			
05:47:56		Crew SPD		265		0.53/ 264	15447			
05:49:40		Crew SPD		240		0.50/ 263	12291			
05:51:36		Crew SPD		238		0.44/ 238	11077			
05:52:00	Terminal	BRRWN				0.43/ 237	10794			Assumed terminal entry time
05:54:27		Crew SPD		217		0.41/ 239	7625			
05:55:20		JMCSY				0.37/ 216	6753			
05:57:36		BRNBX				0.35/ 216	4704			
05:58:02		Crew SPD		210		0.35/ 215	4156			
05:59:00		UPSCO				0.31/ 191	3463			
05:59:03		Crew SPD		177		0.31/ 190	3423			
06:00:11		Crew SPD		157		0.28/ 177	2698			
06:00:40		PARCL				0.25/ 157	2376			
06:00:47		Crew SPD		142		0.24/ 156	2288			
06:03:08		TD								Ownship touchdown

Table D-5. UPS 919 Night 1 Flight Deck Timeline

UPS919 → UPS905 → UPS903 → UPS857 → UPS921

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
02:45	Departure	Wheels up								
03:56	Pre-IM-S AA	IM-S AA instruction received		0.83						
03:21:20		IM Speed	0.81	0.81	1134	0.83/ 297	33010	119	24.2	
03:56										Noticed crew was trying to anticipate next IM Speed (the FO repeatedly mentioned his desire to fly slower than the IM Speed in anticipation that they would catch up or slow down by the time they reached PXV).
03:59:42		IM Speed	0.83	-	-					
04:00:09		IM Speed	0.84	-	-	0.81/ 278	35024	172	16.5	
04:00:37		Crew SPD		0.83		0.82/ 279	35022	172	16.6	
04:11:27		Crew SPD		0.84		0.83/ 284	34994	121	17.2	
04:18:29		IM Speed	0.83	0.83	6	0.85/ 289	35009	93	15.1	
04:24:58		IM Speed	0.79	-	-	0.81/ 275	34983	101	15.8	
04:25:54		Crew SPD		0.80		0.81/ 276	35033	105	16.2	
04:26:53		IM Speed	0.83	0.83	279	0.82/ 278	35014	105	16.3	
04:32										FO mentioned that they want to be slower than IM Speed since they'll eventually have to slow down at the merge. Also, he mentioned it's more economical to stay behind the IM Speed.
04:58										CPT noted picnic table was a little confusing. Incorporating current spacing interval on CDTI (between PT and ownship) would be useful.
05:00:54		IM Speed	0.84	-	-	0.83/ 285	35009	130	19.7	

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:04		ALT change								Climbed to FL370
05:08:30	Achieve	Start IM-S AA				0.83/ 271	37007	134	20.4	Ownship 300 NM from PXV
05:09:39		Crew SPD		0.84		0.83/ 271	37010	137	20.6	Changed to match IM Speed
05:13:14		Crew SPD		0.83		0.85/ 277	37012	136	20.7	
05:13:28		IM Speed	0.83	-	Already Selected	0.85/ 277	37010	134	20.7	
05:24:06		IM Speed	0.79	0.79	5	0.83/ 270	37011	143	20.7	
05:30:18		Crew SPD		0.78		0.80/ 258	37009	142	20.5	
05:37:03		Crew SPD		0.79		0.79/ 255	37008	144	20.9	
05:41:09		TOD1						146	21.1	TOD from FL370
05:41:30		Crew SPD		0.78		0.79/ 256	36652	146	21.1	
05:42:09		Crew SPD		0.76		0.77/ 256	35507	146	21.1	
05:42:15		IM Speed	270	270	13	0.76/ 256	35293	146	21.1	
05:42:22		TOD2						146	21.1	Leaving FL350
05:42:28	Maintain / Initial Descent	PXV						146	21.0	
05:42:29										
05:43:15		IM Speed	285	285	10	0.76/ 269	32718	149	20.9	
05:44:16		IM Speed	300	300	7	0.76/ 287	29787	152	20.4	
05:44:41		IM Speed	320	320	9	0.75/ 292	28386	153	20.0	
05:46:19		IM Speed	305	305	9	0.73/ 319	22983	152	17.7	Crew noted large speed decrease
05:47:04	BRRWN Restriction	IM Speed	290	290	7	0.69/ 306	21718	149	16.6	
05:48:49		IM Speed	270	270	11	0.61/ 291	18191	144	14.5	

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:49:20	Terminal	IM Speed	250	250	8	0.58/ 281	17250	143	14.1	Crew noted that FMC limit was 240.
05:53:14		Crew SPD		240		0.46/ 249	11037	148	12.2	
05:54:07	Arrival Turn	BRRWN				0.44/ 239	11048	147	12.0	
05:55:21		IM Speed	235	235	5	0.43/ 240	9525	147	11.2	
05:57:09		IM Speed	220	220	6	0.41/ 237	7420	147	8.6	
05:57:48		JMCSY				0.38/ 222	6824	145	9.4	
05:57:39		IM Speed	205	205	4	0.39/ 226	6957	146	9.3	
06:00:08	Final Descent	BRNBX				0.34/ 207	2697	148	8.1	
06:01:07		IM Speed	175	175	9	0.33/ 204	3642	150	7.1	
06:01:19		Crew SPD		176		0.33/ 203	3576	149	6.9	
06:01:24		UPSCO				0.32/ 201	3542	149	6.8	
06:02:28		Crew SPD		156		0.28/ 178	3029	147	5.9	
06:02:34		IM Speed	172	-	-	0.28/ 177	2906	147	5.8	
06:03:08	Post IM-S AA	TGT TD				0.24/ 155	2440	147	5.7	Target touchdown
06:03:12		PARCL				0.24/ 155	2422	147	5.7	
06:03:28		Crew SPD		141		0.25/ 158	2229	146	5.5	
06:03:50		1500 AGL				0.22/ 143	2006			Ownship crosses 1500 ft. AGL
06:05:35		TD								Ownship touchdown

Post-flight notes:

- Crew: “Algorithm jumps too often during CDA. The CDA speed always trumps SI.”
- Observer: Both crew members noted a 30-50% increase in workload, mainly due to limited experience.

D.2 Night 2 Flight Deck Timelines

Table D-6. UPS857 Night 2 Flight Deck Timeline

UPS919 → UPS903 → UPS905 → **UPS857** → UPS921

Time (UTC)	Phase	Event	IM Speed Value* (Mach or kts)	Pilot SEL Input* (Mach or kts)	IM Speed Response / Delay (sec)	Estimated Ownship Speed** (KIAS)	Ownship Pressure Altitude** (FT)	RNG to TGT* (NM)	Notes
03:01	Departure	Wheels up							
03:41	Pre-IM-S AA	IM-S AA instruction received							
03:53		IM Speed	225	-	Not selected	232	35034	13.8	Crews experimenting with CDTI and spacing. Input 150 sec spacing with UPS921. When they removed PXV from inputs,, they received IM Speeds.
03:54		IM Speed	211	-	Not selected	231	35024		
03:59		IM Speed	240	-	Not selected	233	35049		
04:00		ATC change							Due to 100kt overtake with UPS921, ZAB requested speed change. Crew responded that they were M&S and ZAB retracted request.
04:00		IM Speed	270	270	?	231	35027	21.3	
04:02		IM Speed	285	285	?	243	35049	21.6	Using DGS to manually maintain spacing. At 04:06, crews put PXV back in M&S input and stopped receiving IM Speeds.
04:34		IM-S AA instruction input							Crew input 145 sec SI for UPS921.
05:01	Achieve	Start IM-S AA							Ownship 300 NM from PXV (estimated)
05:06		IM Speed	285	Already Selected	-	285	35053	24.4	No IM Speed earlier due to “save and exit” interface issue. SEL was 280 before IM Speed.
05:31		IM Speed	291	291	25	282	35050	21.5	
05:32		Crew SPD		285		282	35050		Observer: crew trying to outthink algorithm

*Ownship SafeRoute data not available. IM Speed, SEL, and RNG values based on flight deck observer reports.

**Ownship speed and altitude data obtained through UPS905 SafeRoute TGT aircraft data.

Time (UTC)	Phase	Event	IM Speed Value* (Mach or kts)	Pilot SEL Input* (Mach or kts)	IM Speed Response / Delay (sec)	Estimated Ownship Speed** (KIAS)	Ownship Pressure Altitude** (FT)	RNG to TGT* (NM)	Notes
05:34									Crew noted that even at 285, still closing a bit tight. Still just aft of Picnic Table. Don't want to go to 291.
05:36		IM Speed	0.84	0.84	60	284	35027	19.1	Unclear why IM Speed was reported in Mach. Crew noted that IM Speed exceeded M_{MO}.
05:37		TOD							
05:38		IM Speed	315	315	Assume < 60 sec	275	34403		
05:39	Maintain / Initial Descent	PXV							
05:42		IM Speed	300	300	Assume < 60 sec	315	22518	15.4	
05:43	Terminal								
05:45	BRRWN Restriction	IM Speed	270	270	Assume < 60 sec	302	15372	12.2	
05:46		IM Speed	250	250	Assume < 60 sec	296	13043	11.6	
05:47		IM Speed	240	240	Assume < 60 sec	299	11113	11.2	
05:48	Arrival Turn	BRRWN				253			Assumed terminal entry time
05:52		JMCSY				246			
05:53		IM Speed	225	225	Assume < 60 sec	243	5398	7.8	At Flaps 1
05:53	Final Descent	BRNBX							
05:54		IM Speed	210	210	Assume < 60 sec	243	4402	7.0	
05:54		IM Speed	169	169	75	238	3973	6.3	
05:55		UPSCO							
05:55		IM Speed	168			240	3922	6.0	
05:55		Crew SPD		139		240	3922	6.0	
05:56	Post IM-S AA	PARCL				198			Assumed since TGT TD data not available
05:56		1500 AGL				153	1998	5.3	Ownship crosses 1500 ft. AGL. IM Speeds off.
05:58		TD							Ownship touchdown

*Ownship SafeRoute data not available. IM Speed, SEL, and RNG values based on flight deck observer reports.

**Ownship speed and altitude data obtained through UPS905 SafeRoute TGT aircraft data.

Table D-7. UPS905 Night 2 Flight Deck Timeline

UPS919 → UPS903 → **UPS905** → UPS857 → UPS921

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
02:39	Departure	Wheels up								
03:36	Pre-IM-S AA	IM-S AA instruction received								
03:08:08		IM Speed	0.84	0.84	1	0.83/ 285	35025	504	76.6	
03:53:41		IM Speed	0.83	-	-	0.84/ 287	35043	896	35.3	
03:53:47		IM Speed	0.79	-	-	0.84/ 287	35040	697	35.2	
03:53:56		IM Speed	0.75	-	-	0.84/ 287	35036	461	34.9	
03:54:38		IM Speed	0.71	-	-	0.84/ 288	35038	274	33.8	
04:00:34		Crew SPD		0.82		0.85/ 291	35032	196	25.0	
04:04:20		IM Speed	0.75	-	-	0.82/ 279	35023	164	22.2	
04:05:16		IM Speed	0.79	-	-	0.82/ 278	35025	162	22.4	
04:06:59		IM Speed	0.83	-	-	0.82/ 279	35029	157	22.5	
04:09										CPT asked if they should follow IM Speeds. FO suggested follow IM Speeds during descent or if range to target not in compliance with 22 NM goal.
04:12										Noted that DGS is 2 kts, and so crew decided to ignore IM Speed.
04:16										Pilots managing speed to maintain ~ 22 NM
04:27:57		Crew SPD		0.81		0.83/ 283	35033	155	21.7	
04:32:34		Crew SPD		0.82		0.81/ 277	35030	156	22.0	
04:36:28		Crew SPD		0.81		0.83/ 282	35043	154	21.8	
04:38:09		Crew SPD		0.80		0.81/ 275	35007	154	21.7	

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
04:40:39		Crew SPD		0.81		0.81/ 274	35040	159	22.1	
04:43:56		IM Speed	0.81	-	Already Selected	0.82/ 280	35034	160	22.2	
04:46:04		Crew SPD		0.80 ↔0.83		0.83/ 282	35035	160	21.9	Several more crew speed changes through 05:04; IM Speed stayed at 0.81.
05:04:48	Achieve	Start IM-S AA						169	23.3	Ownship 300 NM from PXV
05:05:04		Crew SPD		0.84		0.83/ 284	35029	171	23.3	
05:08:40		Crew SPD		0.83		0.85/ 290	35038	160	23.1	
05:09:12		Crew SPD		0.84		0.85/ 289	35034	160	23.0	
05:18:54		Crew SPD		0.82		0.84/ 289	35036	153	21.9	PF seems to be adjusting speed based on distance as agreed to by group (to maintain ~ 22 NM in trail spacing).
05:21:17		Crew SPD		0.83		0.82/ 279	35026	154	22.0	
05:27:40		IM Speed	0.84	-		0.84/ 286	35040	155	22.0	Crew dwelled on 0.82 then 0.83 on the way up to 0.84.
05:27:47		Crew SPD		0.82		0.84/ 286	35038	155	21.9	
05:28:44		Crew SPD		0.83		0.83/ 282	35025	155	22.0	
05:31:23		Crew SPD		0.84		0.84/ 284	35038	156	22.0	
05:31										PM suggested start following IM Speeds to move up picnic table
05:33:43		Crew SPD		0.83		0.84/ 287	35020	156	21.8	
05:35:24		Crew SPD		0.84		0.83/ 285	35027	155	21.7	
05:39:40	Maintain	PXV						153	21.1	TOD just before PXV
05:39:40		Crew SPD		0.80		0.83/ 285	34913	153	21.1	
05:40:18		Crew SPD		0.84		0.80/ 277	33897	152	21.1	
05:40:39		Crew SPD		0.83		0.80/ 290	32490	152	21.0	
05:40:47	Initial Descent	IM Speed	314	314	48	0.82/ 300	31746	152	21.0	
05:41:55		Crew SPD		316		0.79/ 313	28309	152	20.2	

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:42:02		Crew SPD		317		0.79/ 312	28026	152	20.1	
05:42:13		Crew SPD		314		0.79/ 315	27430	152	20.0	
05:42:33		Crew SPD		317		0.77/ 315	26541	152	19.7	
05:42:42		Crew SPD		314		0.77/ 314	26221	152	19.6	
05:43:41		Crew SPD		318		0.73/ 313	23914	153	18.9	
05:43:49		Crew SPD		314		0.73/ 315	23573	153	18.8	
05:44										PNF suggested adding speed brakes to get back down to path
05:45:01		Crew SPD		320		0.69/ 315	20753	154	17.8	
05:45:07		Crew SPD		317		0.68/ 313	20529	154	17.7	
05:45:13		Crew SPD		322		0.68/ 314	20253	154	17.6	
05:45:22		Crew SPD		317		0.68/ 316	19777	154	17.4	
05:45	Terminal									
05:45:37		Crew SPD		314		0.67/ 317	19076	154	17.2	
05:46										PF adds speed breaks
05:47:14		IM Speed	315	315	6	0.62/ 314	15307	154	15.6	
05:48:35		Crew SPD		310		0.59/ 314	12339	151	13.8	
05:48:42		Crew SPD		315		0.59/ 315	12087	151	13.6	
05:49:02	BRRWN Restriction	Crew SPD		240		0.58/ 314	11393	150	13.1	
05:49:10		IM Speed	260	-	-	0.57/ 310	11179	150	12.9	Not selected since SEL was already set at 240
05:49:20		Crew SPD		239		0.56/ 303	11018	150	12.7	
05:49:22		IM Speed	250	250	17	0.55/ 301	10998	149	12.6	
05:49:35		Crew SPD		286		0.53/ 287	10961	150	12.4	
05:49:51		Crew SPD		240		0.50/ 274	10868	150	12.2	Observer: crew seem to by flying relative to picnic table

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:50:36	Arrival Turn	BRRWN				0.47/ 258	10230	149	11.8	
05:50:40		Crew SPD		253		0.47/257	10195	149	11.7	
05:50:50		IM Speed	245	-	-	0.46/ 251	10131	149	11.7	Cleared for approach
05:54:23		JMCSY				0.41/ 241	6169	148	10.7	
05:54:25		Crew SPD		213		0.41/ 241	6128	148	10.8	Speed breaks to full slow; crew feels CDA is too steep and thus they are carrying too much speed
05:54:59		Crew SPD		214		0.37/ 222	5764	150	11.0	
05:55:57		Crew SPD		192		0.35/ 214	4397	156	10.9	
05:56:26		IM Speed	250	-	-	0.34/ 211	3812	160	10.6	
05:56:39	Final Descent	BRNBX				0.34/ 211	3570	162	10.4	
05:56:42		Crew SPD		173		0.34/ 210	3522	162	10.3	
05:57:07		Crew SPD		174		0.30/ 185	3477	166	10.0	
05:58:00		IM Speed	195	-	-	0.29/ 177	3577	179	9.4	
05:58:08		UPSCO				0.28/ 176	3681	181	9.3	
05:58:51	Post-IM-S AA	TGT TD				0.28/ 175	3165	191	8.7	Target touchdown
05:58:56		IM Speed	167	-	-	0.28/ 175	3082			
05:59:09		Crew SPD		153		0.28/ 174	2880			
05:59:34		Crew SPD		138		0.24/ 153	2498			
05:59:44		PARCL				0.23/ 144	2342			
05:59:58		IM Speed	166	-	-	0.22/ 139	2162			
06:00:11		1500 AGL				0.22/ 139	2000			Ownship crosses 1500 ft. AGL
06:02:15		TD								Ownship touchdown

Table D-8. UPS903 Night 2 Flight Deck Timeline

UPS919 → **UPS903** → UPS905 → UPS857 → UPS921

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
02:40	Departure	Wheels up								
03:32:20		IM Speed	0.84	0.84	61	0.82/ 279	35012	151	21.6	
03:43	Pre-IM-S AA	IM-S AA instruction received								
04:10:03		Crew SPD		0.82		0.82/ 280	35016	141	20.1	Numerous changes (M0.84 +/- M0.01, M0.02) in SEL speeds recorded during previous 36 min.
04:40:28		IM Speed	0.80	0.80	6	0.83/ 284	34997	141	19.3	
05:07:32	Achieve	Start IM-S AA						163	22.8	Ownship 300 NM from PXV
05:07:35		IM Speed	0.84	0.84	14	0.81/ 275	35021	163	22.8	
05:12:49		IM Speed	290	290	4	0.85/ 289	34974	140	19.6	Mach/ IAS changeover
05:40:12		TOD						140	19.7	
05:42:04	Maintain	PXV						140	19.4	
05:42:06	Initial Descent	IM Speed	275	275	7	0.81/ 288	32973	140	19.4	
05:42:59		IM Speed	290	290	7	0.76/ 278	31686	141	19.4	
05:43:34		IM Speed	305	305	11	0.76/ 292	29434	143	19.4	
05:44:31		IM Speed	320	320	6	0.75/ 304	26684	146	19.2	Observer: Pulling back on throttles

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:47	Terminal									Observer: "50 kt overtake, they're not worried! They're learning!"
05:51:22	BRRWN Restriction	IM Speed	265	265	13	0.60/ 320	11800	145	13.0	
05:52:35		IM Speed	250	250	6	0.50/ 272	11085	142	11.5	
05:53:00	Arrival Turn	BRRWN				0.47/255	11022	142	11.3	
05:53:18		IM Speed	235	235	7	0.46/ 249	10901	142	11.1	Observer: Speed brakes applied
05:56:48		JMCSY				0.40/238	6682	145	9.4	
05:57:02		IM Speed	220	-	-	0.40/ 237	6443	145	9.5	
05:57:09		Crew SPD		218		0.40/ 237	6310	145	9.4	
05:58:14		IM Speed	205	205	10	0.36/ 218	5445	143	8.4	
05:59:00	Final Descent	BRNBX				0.34/206	4664	142	7.8	
05:59:08		IM Speed	174	174	45	0.34/ 206	4509	142	7.6	
06:00:31		UPSCO				0.29/ 176	3839	140	6.7	
06:01:34		IM SPD	173	-	-	0.28/ 174	2848	141	6.0	
06:01:38		Crew SPD		170		0.28/ 174	2791	141	6.0	
06:01:56		PARCL				0.27/ 171	2517	140	5.8	
06:01:58		Crew SPD		157		0.27/ 171	2483	139	5.7	
06:02:15	Post-IM-S AA	TGT TD					2204	137	5.6	Target touchdown
06:02:25		IM SPD	172	-	-	0.25/ 157	2056			
06:02:29		1500 AGL				0.25/ 157	1997			Ownship crosses 1500 ft. AGL
06:02:36		Crew SPD		142		0.25/ 157	1898			
06:04:13		TD								Ownship touchdown

Table D-9. UPS 919 Night 2 Flight Deck Timeline

UPS919 → UPS903 → UPS905 → UPS857 → UPS921

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
02:45	Departure	Wheels up								
03:12	Pre-IM-S AA	IM-S AA instruction received								
03:12:58		IM Speed	0.80	-	-	0.83/ 298	33017	135	37.4	Not selected. Current Mach = .84 to catch up to UPS903
03:13:01		Crew SPD		0.84		0.84/ 298	33016	125	37.4	
03:28:24		Crew SPD		0.80		0.85/ 302	33009	157	25.0	
03:32:33		Crew SPD		0.84		0.81/ 287	33016	156	24.7	
03:52										FO mentioned he did not like the AGD when engaged but not captured. The screen should be blank but display .80 mach as default.
04:33:35		Crew SPD		0.82		0.85/ 290	35002	142	20.0	
04:34:15		IM Speed	0.83	0.83	19	0.83/ 284	34990	132	20.0	Crew re-engaged system and got .83 IM Speed
04:43										Observer: Seems AGD is not working correctly. Ownship has 30 kts overtake on 903,but it is still commanding .83.
04:45:44		IM Speed	0.79	0.79	7	0.83/ 283	34993	130	17.4	
04:47		ALT change								Crew requested FL370 out of FL350 for fuel econ. ATC granted
05:09:36		Crew SPD		0.83		0.79/ 258	36999	148	20.6	Crew increased to .83 because AGD was not providing IM Speeds and ownship had 40 kts overtake on UPS903

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:09:50	Achieve	Start IM-S AA						149	20.8	Ownship 300 NM from PXV
05:12:04		IM Speed	0.84	0.84	9	0.84/ 274	36993	150	21.9	Crew noted they did not like large IM Speed jump (.79 -> .84)
05:15:37		TOD1								TOD from FL370
05:44:40	Maintain	PXV						167	22.2	
05:45:01		TOD2								TOD from FL350
05:46:02	Initial Descent	IM Speed	310	310	13	0.83/300	32321	163	21.5	
05:46:49		IM Speed	329	-	-	0.82/ 313	29586	159	20.8	Not selected. Observer: it appears crew is using distance as primary mechanism for spacing.
05:50										Observer: Crew concluded AGD wasn't working and decided to start ignoring IM Speeds.
05:51:51		IM Speed	345	-	-	0.65/ 318	16798	161	17.3	
05:53:58	BRRWN Restriction	IM Speed	295	-	-	0.60/ 323	11944	159	14.1	
05:54:01		Crew SPD		240		0.60/ 321	11868	159	14.1	
05:54:59		IM Speed	275	-	-	0.51/ 279	11280	159	12.7	
05:55:32		IM Speed	250	-	-	0.48/ 259	10996	158	12.3	

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:55:32	Arrival Turn	BRRWN				0.48/ 259	10996	158	12.3	Assumed terminal entry time
05:57:20		IM Speed	245	-	-	0.43/ 243	8895	153	10.4	
05:59:28		JMCSY				0.39/ 230	6556	153	10.1	
05:59:31		IM Speed	230	230	51	0.39/ 231	6508	153	10.2	
06:00:38		IM Speed	215	215	13	0.39/ 236	5382	148	8.8	
06:01:06		Crew SPD		195		0.37/ 224	4992	146	8.1	
06:01:24	Final Descent	BRNBX				0.35/ 211	4762	145	7.8	
06:01:34		IM Speed	172	-	-	0.34/ 204	4640	145	7.7	
06:02:22		Crew SPD		175		0.31/ 191	3984	144	7.3	
06:02:56		UPSCO				0.29/ 178	3691	143	7.0	
06:04:10		Crew SPD		155		0.27/ 174	2491	142	6.2	
06:04:11		IM Speed	170	-	-	0.27/ 173	2469	142	6.2	
06:04:13	Post-IM-S AA	TGT TD				0.27/ 172	2427	142	6.2	Target touchdown
06:04:24		PARCL				0.26/ 164	2254			
06:04:42		1500 AGL				0.24/ 155	1995			Ownship crosses 1500 ft. AGL
06:04:45		Crew SPD		140		0.24/ 155	1949			
06:06:41		TD								Ownship touchdown

Post-flight notes:

- Crew (same as Night 1): “Algorithm did not seem to produce accurate IM Speeds.”
- Observer: Both crew members noted a 30% - 50% increase in workload.

D.3 Night 3 Flight Deck Timelines

Table D-10. UPS921 Night 3 Flight Deck Timeline

UPS919 → UPS905 → UPS903 → UPS857 → **UPS921** → UPS957

Time (UTC)	Phase	Event	IM Speed Value* (Mach or kts)	Pilot SEL Input* (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed* (KIAS)	RNG to TGT* (NM)	Notes
02:29	Departure	Wheels up						
?	Pre-IM-S AA	IM-S AA instruction received						Time not recorded.
04:41							33.2	Initiated M&S behind UPS957; GS +35 kts
04:47		Crew SPD		0.80 → 0.78				To allow followers to catch up
04:49		IM Speed	255	255	3 min delay		28.1	
04:58		Crew SPD		265			26.9	Crew felt they had to speed up as they were not catching up to their lead
04:58	Achieve	Start IM-S AA						Ownship 300 NM from PXV (estimated)
04:58		IM Speed	260	260	Assume < 60 sec		26.6	Crew reinitialized system
05:04		Crew SPD		264			24.5	
05:08		Crew SPD		260			24.5	
05:16		Crew SPD		275			22.5	
05:17		Crew SPD		280				
05:19		IM Speed	275	275	Assume < 60 sec		22.5	
05:28		IM Speed	291	291	Assume < 60 sec		22.0	
05:35	Maintain	PXV						TOD just after
05:36							20.0	Observer: Speed brakes on

*Ownship SafeRoute data not available. IM Speed, SEL, Speed, and RNG values based on flight deck observer reports.

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed* (KIAS)	RNG to TGT* (NM)	Notes
05:38	Initial Descent	IM Speed	310	310	Assume < 60 sec			Observer: Speed brakes off
05:39		IM Speed	325	325	Assume < 60 sec	320	18.1	Current KIAS noted by observer
05:43		IM Speed	310	310	Assume < 60 sec		14.9	Pilot reported being in the lead's wake and thus added speed brakes to slow descent.
05:44						312		
05:45	BRRWN Restriction	IM Speed	260	260	Assume < 60 sec	281	12	
05:46	Arrival Turn	BRRWN						Terminal entry time recorded by observer
05:46		IM Speed	245	245	Assume < 60 sec	247	11.4	
05:48							9.1	
05:49		IM Speed	230	230	Assume < 60 sec	238	10.4	
05:49		JMCSY				238	9.3	Observer: Speed brakes on
05:52	Final Descent	BRNBX						
05:53		UPSCO						
05:53		IM Speed	170	170	Assume < 60 sec	230	7.1	
05:54		IM Speed	162	162	Assume < 60 sec	150	6.5	Final observed AGD range = 6.5
05:54	Post-IM-S AA	PARCL				150		Assumed since TGT TD data not available
05:57		TD						Ownship touchdown

Post-flight notes:

- Pilot commented that workload was too high during the arrival; "you have to keep on top of it to follow the speed"; PNF agreed that workload was too high. Both suggested that more speed commands may help.

Table D-11. UPS857 Night 3 Flight Deck Timeline

UPS919 → UPS905 → UPS903 → **UPS857** → UPS921 → UPS957

Time (UTC)	Phase	Event	IM Speed Value* (Mach or kts)	Pilot SEL Input* (Mach or kts)	IM Speed Response / Notes	Estimated Ownship Speed** (KIAS)	Ownship Pressure Altitude** (FT)	RNG to TGT* (NM)	Notes
03:01	Departure	Wheels up							
04:40	Pre-IM-S AA	IM-S AA instruction received							
04:40		IM Speed	275	275		274	35050		
05:04	Achieve	Start IM-S AA							Ownship 300 NM from PXV**
05:28		IM Speed	290	-	-	274	35051	22.0	
05:28		Crew SPD		285					
05:32		IM Speed	291	-	-	287	35049	22.0	
05:32		Crew SPD		280					
05:34		Crew SPD		283		287	35049	22.5	
05:36		Crew SPD		288		278	35049		
05:38		TOD							
05:39		Crew SPD		295		289	34359	20.9	
05:40	Maintain / Initial Descent	PXV							
05:42		IM Speed	350	-	-	299	25746	19.7	
05:42		Crew SPD		334					
05:43		IM Speed	357	-	-	325	21810	19.3	
05:43		Crew SPD		342					
05:45		IM Speed	355	-	-	349	15697	15.7	
05:45		Crew SPD		338					

*Ownship SafeRoute data not available. IM Speed, SEL, and RNG values based on flight deck observer reports.

**Data obtained through UPS903 SafeRoute TGT aircraft data.

Time (UTC)	Phase	Event	IM Speed Value* (Mach or kts)	Pilot SEL Input* (Mach or kts)	IM Speed Response / Notes	Estimated Ownship Speed** (KIAS)	Ownship Pressure Altitude** (FT)	RNG to TGT* (NM)	Notes
05:47	BRRWN Restriction	IM Speed	280	-	-	350	11100	12.7	
05:47		Crew SPD		240					
05:48	Arrival Turn	BRRWN							Assumed terminal entry time
05:48		IM Speed	250	250	Assume < 60 sec	307	11100	12.4	
05:52		IM Speed	235	235	Assume < 60 sec	246	7070	10.4	
05:52		JMCSY							
05:54	Final Descent	BRNBX							
05:55		Crew SPD		194		231	4075	7.7	
05:55		UPSCO							
05:56		IM Speed	168	-	-	221	3401	5.3	Final (observer) recorded AGD range = 5.3
05:56		Crew SPD		138					
05:56		PARCL							
05:57	Post-IM-S AA	TGT TD							Target touchdown
05:57		1500 AGL				136	1998		Ownship crosses 1500 ft. AGL
05:59		TD							Ownship touchdown

*Ownship SafeRoute data not available. IM Speed, SEL, and RNG values based on flight deck observer reports.

**Data obtained through UPS903 SafeRoute TGT aircraft data.

Table D-12. UPS903 Night 3 Flight Deck Timeline

UPS919 → UPS905 → **UPS903** → UPS857 → UPS921 → UPS957

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
02:34	Departure	Wheels up								
04:13										FO: frustrating to have to cycle through all a/c to find the one that's wanted.
04:40:28		IM Speed	0.83	-	-	0.83/ 281	35002	249	41.9	
04:41:03		Crew SPD		0.85		0.82/281	35001	249	41.5	
04:42:39		Crew SPD		0.84		0.84/ 287	34977	249	40.5	
04:44:37		Crew SPD		0.83		0.84/ 288	35006	246	39.3	
04:48	Pre-IM-S AA	IM-S AA instruction received								
04:51:48		IM Speed	280	-	-	0.84/ 286	35005	230	34.6	MACH / IAS Transition
04:51:48		Crew SPD		286		0.84/ 286	35005	230	34.6	
04:59:05		IM Speed	265	265	47	0.78/ 266	35025	212	28.2	
05:03:58	Achieve	Start IM-S AA						207	27.6	Ownship 300 NM from PXV
05:09:21		Crew SPD		275		0.79/ 270	35011	195	25.9	Crew concerned IM Speed is too slow. Uncommanded speed change as a test.
05:15:52		Crew SPD		265		0.81/ 275	35010	170	22.0	Slowed to get back to IM Speed
05:26:18		IM Speed	280	280	8	0.78/ 265	35001	161	21.9	
05:32:25		IM Speed	291	291	6	0.82/ 278	35008	158	22.3	
05:40:39	Maintain	PXV						151	21.0	
05:41:22	Initial Descent	TOD						150	20.6	

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:44:48		IM Speed	345	-	-	0.69/ 292	23965	151	18.9	
05:45:10		Crew SPD		344		0.68/ 295	22802	152	19.0	
05:49:29	BRRWN Restriction	Crew SPD		240		0.64/ 345	11664	147	14.4	
05:49:41		IM Speed	270	-	-	0.62/ 339	11303	147	14.0	Not selected
05:51:02		IM Speed	255	-	-	0.48/ 262	11077	148	12.4	
05:51:12	Arrival Turn	BRRWN				0.47/ 254	11076	149	12.3	Assumed terminal entry time
05:51:29		IM Speed	250	250	16	0.45/ 242	10994	149	12.3	
05:54:56		JMCSY				0.42/ 251	6376	151	11.1	
05:56:47		IM Speed	240	240	8	0.41/ 251	4194	148	9.7	
05:56:50	Final Descent	BRNBX				0.41/ 250	4140	148	9.6	
05:58:01		IM Speed	175	-	-	0.39/ 239	3873	146	7.5	
05:58:04		UPSCO				0.39/ 238	3837	145	7.4	
05:58:15		Crew SPD		199		0.39/ 241	3583	145	7.0	
05:58:54		Crew SPD		177		0.34/ 216	2767	141	5.9	
05:59:02		IM Speed	172	-	-	0.32/ 205	2618	140	5.7	
05:59:05		Crew SPD		160		0.32/ 201	2562	139	5.6	
05:59:12		PARCL				0.30/ 192	2432	138	5.5	
05:59:23	Post-IM-S AA	TGT TD				0.28/ 177	2237	137	5.4	Target touchdown
05:59:24		Crew SPD		157		0.28/ 176	2224			
05:59:39		1500 AGL				0.26/ 164	2000			Ownship crosses 1500 ft. AGL
05:59:49		Crew SPD		141		0.25/ 157	1849			
06:01:31		TD								Ownship touchdown

Table D-13. UPS905 Night 3 Flight Deck Timeline

UPS919 → **UPS905** → UPS903 → UPS857 → UPS921 → UPS957

Time (UTC)	Phase	Event	IM Speed Value* (Mach or kts)	Pilot SEL Input* (Mach or kts)	IM Speed Response / Delay	Estimated Ownship Speed** (KIAS)	Ownship Pressure Altitude** (FT)	RNG to TGT* (NM)	Notes
02:39	Departure	Wheels up							
04:40	Pre-IM-S AA	IM-S AA instruction received							
05:00		IM Speed	.84	.84	Assume < 60 sec	286	35000	24	
05:03		IM Speed	.81	.81	Assume < 60 sec	284	35000		
05:09	Achieve	Start IM-S AA							Ownship 300 NM from PXV**
05:35		IM Speed	305	305	Assume < 60 sec	278	35000	19.8	
05:45	Maintain	Crossed PXV							TOD just after
05:46	Initial Descent	IM Speed	290	290	Assume < 60 sec	317	27105		
05:47		IM Speed	330	330	Assume < 60 sec	309	24550	18.6	
05:48		IM Speed	345	345	Assume < 60 sec	301	21923		
05:52	BRRWN Restriction	IM Speed	275	275	Assume < 60 sec	359	11987	13.7	
05:53	Arrival Turn	BRRWN				313			Assumed terminal entry time
05:56		IM Speed	250	250	Assume < 60 sec	236	8323	11.3	
05:57		JMCSY				235			
05:59	Final Descent	BRNBX				238			
06:00		UPSCO				229			
06:01		IM Speed	175	175	Assume < 60 sec	206	3461	7.9	
06:01		PARCL				206			
06:01	Post-IM-S AA	TGT TD				198	2847	5.8	Target touchdown.
06:02		IM Speed	169	169	Assume < 60 sec	174	2345		
06:02		1500 AGL				154	1999		Ownship crosses 1500 ft. AGL
06:04		TD							Ownship touchdown

*Ownship SafeRoute data not available. IM Speed, SEL, and RNG values based on flight deck observer reports.

**Data obtained through UPS919 SafeRoute TGT aircraft data.

Table D-14. UPS919 Night 3 Flight Deck Timeline

UPS919 → UPS905 → UPS903 → UPS857 → UPS921 → UPS957

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
02:46	Departure	Wheels up								
03:15	Pre-IM-S AA									Pilots initiate IM-S AA with 905, but do not start seeing IM Speeds yet.
04:40		IM-S AA instruction received		0.82						The crew thought they should receive speed commands after initiating FIM equipment early on, soon after top of climb. Then, speed advisories were displayed but seemed incorrect (i.e. a speed-up was displayed when this would have led to a spacing that was too close, at least by judgment of the crew). Finally, after reengaging the equipment two more times, speed advisories were given that actually matched what the crew had currently selected
04:51:35		IM Speed	0.84	-	-	0.83/283	35019	298	43.5	
04:51:56		IM Speed	0.83	-	-	0.83/ 284	35000	108	16.0	The flight crew did not follow speed advisories, because it did not match the spacing that the crew attempted to maintain. UPS 919 had so far attempted to increase the spacing behind 905 who had started late and was still increasing its spacing. Based on that, the crew thought they were already too close behind 905 and were waiting for it to increase the spacing further. The crew clearly second-guessed the FIM systems speed advisories and wanted to see if they made sense before implementing IM Speeds. Also, the crew appeared to already mistrust the system somewhat because it had not given speed commands earlier when they had expected them. Therefore, the crew had started to rely on the display of closure rate and displayed distance for their speed interventions

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:08:56	Achieve	Start IM-S AA								Ownship 300 NM from PXV
05:16:02		Crew SPD		0.81		0.83/ 283	35011	121	16.7	IM Speed was still 0.83 Mach. Crew uses displayed distance on AGD to “adjust” their speed instead of the speed commands
05:18:33		Crew SPD		0.80		0.81/ 275	35006	121	16.7	
05:21:00		Crew SPD		0.78		0.80/ 273	35009	124	16.9	
05:22:10		IM Speed	0.80	0.80	29	0.79/ 267	35000	128	17.1	FIM reinitation gives a speed command of M 0.80. Crew comments “our trust into IM Speeds is low” but trust into the display of the distance on AGD is fine. This speed advisory confirmed the flight crew’s expectation about the system. The IM Speeds from before did not seem to make sense, and eventually, the FIM system “had come around”, and advised a speed that the flight crew had already implemented, based on their expectations.
05:40:43		IM Speed	0.84	0.84	12	0.81/ 274	34998	145	20.5	Crew felt this was too large a jump, but still complied.
05:45:35	Maintain	PXV						149	21.0	
05:45:46		TOD						149	20.9	
05:46:21		IM Speed	0.78	0.78	5	0.82/ 287	34073	146	20.6	
05:47:34	Initial Descent	IM Speed	300	300	9	0.78/ 296	30064	152	19.8	
05:48:30		IM Speed	315	315	9	0.74/ 299	27099	153	19.0	
05:51:01		IM Speed	345	-	-	0.69/ 314	20833	149	18.5	Crew feels it is “no good” to accelerate during the descent phase of flight
05:52:51		IM Speed	357	-	-	0.64/ 315	16798	156	18.4	
05:54:13		IM Speed	335	-	-	0.60/ 315	13396	163	16.8	
05:54:39	BRRWN Restriction	Crew SPD		240		0.59/ 313	12458	165	16.1	
05:55:33		IM Speed	285	-	-	0.53/ 288	11464	170	14.7	

Time (UTC)	Phase	Event	IM Speed Value (Mach or kts)	Pilot SEL Input (Mach or kts)	IM Speed Response / Delay (sec)	Ownship Speed (Mach / KIAS)	Ownship Pressure Altitude (FT)	Time Spacing (sec)	RNG to TGT (NM)	Notes
05:56:27	Arrival Turn	BRRWN				0.46/ 251	11042	173	13.8	Assumed terminal entry time
05:56:45		IM Speed	250	-	-	0.44/ 240	10998	174	13.8	
5:56:59		Crew SPD		217		0.44/ 239	10724	174	13.7	
05:58:30		Crew SPD		230		0.40/ 226	8852	179	11.3	
06:00:40		JMCSY				0.39/ 230	6651	190	13.6	
06:02:27		Crew SPD		210		0.38/ 229	4811	193	11.7	
06:02:32	Final Descent	BRNBX				0.37/ 228	4721	193	11.6	
06:03:32		IM Speed	230	-	-	0.34/ 208	4090	194	10.0	
06:03:53		UPSCO				0.35/ 213	3873	194	9.6	
06:04:16	Post-IM-S AA	TGT TD				0.35/ 218	3421	194	9.0	Target touchdown
06:04:20		Crew SPD		176		0.35/ 218	3344			
06:04:40		IM Speed	215	-	-	0.35/ 218	2972			
06:04:57		IM Speed	200	-	-	0.32/ 204	2630			
06:05:04		PARCL				0.31/ 199	2502			
06:05:15		Crew SPD		156		0.30/ 189	2298			
06:05:33		1500 AGL				0.27/ 172	2010			Ownship crosses 1500 ft. AGL
06:05:41		Crew SPD		141		0.26/ 165	1880			
06:07:24		TD								Ownship touchdown

Post-flight notes:

- Additional crew comment: “Our AGD commanded max speed the final night even though we were less than 20 miles from the target plane at TOD. We did lose space on that airplane because they kept their speed up on the descent and they were not at 240 IAS when they passed the first waypoint.”

Appendix E Field Test Team Members and Data Collection and Analysis Contributors

The following individuals participated in test planning, execution, data reduction and analysis, and documentation. Organizations are as of the time of each individual's involvement in the test and initial report generation.

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