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PRECISION AIRDROP SYSTEM
AN EMERGING OPERATIONAL CAPABILITY

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1. INTRODUCTION

Traditional Air Force tactics conduct ballistic re-supply airdrops and humanitarian relief airdrop missions by aircraft operating at low altitudes and slow airspeeds in order to maximize delivery accuracy. This flight profile places aircraft at significant risk in high threat environments, over mountainous or rough terrain, or in marginal weather conditions. Air operations in Bosnia, Kosovo, and Afghanistan underscored the need for a precision aerial delivery capability operating from high altitude. The Precision Airdrop System (PADS) facilitates ballistic and guided cargo delivery accuracy and reduces vulnerability of airdrop aircraft by enabling them to remain near their upper altitude limit for airdrop. PADS also permits cargo delivery from maximum stand-off ranges. The Air Force Office of Scientific Research (AFOSR) New World Vistas-Precision Aerial Delivery Program sponsored PADS development and testing in concert with the Airdrop/Aerial Delivery Directorate, Natick Soldier Center, US Army Soldier and Biological Chemical Command. The research and development results of that initiative advanced the state-of-the-art for determining the Computed Air Release Point (CARP) by application of atmospheric technologies to support high-fidelity load release and descent trajectory modeling in real time onboard the airdrop aircraft or at an alternate location in a net-centric environment. An additional result increased understanding of how the natural variability of the atmosphere, over all terrain environments, influences the impact accuracy prediction of heavy loads delivered from high altitudes. Numerous test events demonstrated the accuracy that can be achieved through application of these technologies. Planning Systems Incorporated (PSI), Reston, Virginia, Draper Laboratory, Cambridge, Massachusetts, and the NOAA Forecast Systems Laboratory, Boulder, Colorado, cooperated on the project. Over 5 years of rigorous development, demonstration, and testing aboard C-130 and C-17 aircraft at Yuma Proving Ground (YPG), Arizona, and Edwards Air Force Base, California, validated the capability of delivering ballistic payloads from altitudes at or above 25,000 feet pressure altitude within average accuracy tolerances of 400 meters.

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2. BACKGROUND

Basic airdrop mission events handled by PADS are shown in the diagram at Figure 1; Computed Air Release Point (CARP) Green Light, payload roll-out, canopy opening and descent trajectory to ground impact. Prototype ballistic parachute PADS development began in 1998. Draper Laboratory and PSI software was implemented on separate laptop computers connected by Ethernet. In-situ atmospheric soundings were made using engineering-level dropsondes. By early 2003, research, development

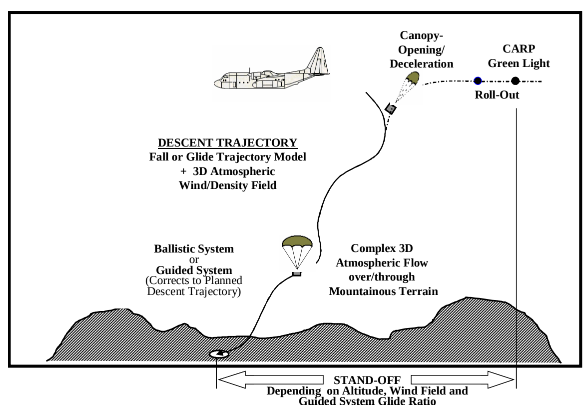

Figure 1. Typical Airdrop Events Treated in PADS

and testing had progressed to an operational design. All PADS software was integrated onto one laptop computer and user interfaces were developed to the standards of fielded systems. Operationally capable, hand-launched dropsondes were produced by PSI and rigorously tested. Finally, PADS functionality was adapted to fit aboard both C-130 and C-17 aircraft. In September 2003, a C-17 operational utility evaluation was conducted at YPG, Arizona, to validate PADS readiness for an operational role aboard line Air Force aircraft.

3. COMPONENTS AND FEATURES

PADS is a man-portable, roll-on/roll-off, snap-on/snap-off laptop computer configuration compatible with airdrop operations on C-130 and C-17 aircraft. The PADS basic hardware components are shown in Figure 2; IBM T30 laptop computer, PADS Interface Processor, UHF antenna connection interface, power strip, hand launched dropsonde, PADS Fly Away Kit carrying case. Also included (not shown) are 1553 PCMCIA data bus card and data bus connectors/cabling.

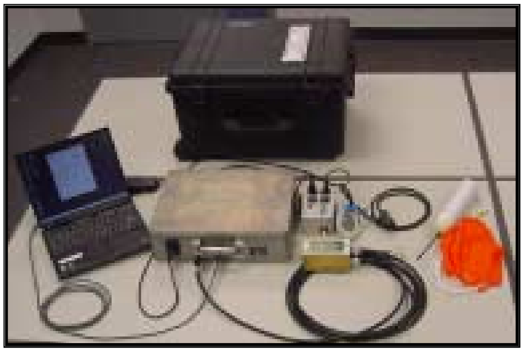

Figure 2. PADS Fly-Away Kit:
Flight-Certified for the C-130 and the C-17

PADS includes a laptop computer-based mission planning system designed for pre-takeoff planning, in-flight updates, and mission execution decisions. Precision is achieved through an atmospheric modeling tool called WindPADS. This is an IBM ThinkPad-based software package developed by PSI. WindPADS is used aboard the airdrop aircraft to assimilate forecast high-resolution 4-dimensional weather data (u-v winds, pressure density), high-resolution topographic data, and real-time in-situ data observed near the drop zone. The Local Analysis and Prediction System (LAPS)[1-5], developed by the National Oceanographic and Atmospheric Administraion (NOAA) Forecast Systems Laboratory (FSL), was tailored by FSL for integration into PADS for use as the atmospheric data assimilation algorithm. In-situ data from dropsondes are acquired onboard the airdrop aircraft for PADS processing using the PADS Interface Processor hardware.

The current tailored LAPS algorithm assimilates high-resolution forecast fields from the Air Force Weather Agency (AFWA) with in-situ wind data at the time of dropsonde (or radiosonde) data. The assimilation is accomplished over a high-resolution (1.0-kilometer) topography field and mass-balance/flow constraints are applied to produce a three-dimensional (3D) field of horizonatal winds, pressure and density parameters. Parameter tendencies, from the forecast fields, at each 3D grid point are used to extrapolate the parameters to the planned payload drop time, normally on the order of 30 minutes after dropsonde release time. The tailored LAPS algorithm also produces parameter unceraInty estimates. The extrapolated forecast 3D field, along with aircraft heading, airspeed, altitude, payload weight, payload roll-out time and parachute opening and drag information, is used by the Precision Airdrop Planning System (PAPS) developed by Draper Laboratory. PAPS simulates aircraft flight path and payload trajectory to produce the CARP for a planned Point of Impact (PI). PAPS also applies a Monte Carlo routine to uncertainties of all components of the airdrop system, including atmospheric parameter uncertainties, to produce impact point error ellipses around the planned PI.

Location coordinates of the CARP generated in-flight, using WindPADS and PAPS, are conveyed to the flight crew for insertion into the aircraft navigation system. This enables flight of the carrier aircraft to, and payload release, at the PADS computed CARP following standard C-130 or C-17 airdrop procedures. The CARP, along with impact point error estimates, guide airdrop decisions (yes/no, time of day and location). PAPS also includes impact point prediction for failed chutes (streamers and detached chutes) and displays aircraft track over maps or images of the drop zone. Systems now being developed and tested will be adapted for wireless communications and in-flight mission planning for guided delivery platforms, high-altitude un-pressurized operations, simultaneous receipt and assimilation of environmental data from multiple sources at different times, and integration of a secure airborne digital communications system for acquisition of environmental data from other than self-deployed dropsondes.

Connectivity and data flow of the PADS components are shown in Figure 3. High-resolution model data from the Air Force Weather Agency (AFWA) create a 4-dimensional mesoscale forecast field at 5.0- kilometer resolution. Wind data from hand-launched dropsondes, aircraft 1553 data bus data, pilot reports, and other in-situ environmental data may be received and processed during CARP calculations. Location coordinates of CARPs generated in-flight using WindPADS and PAPS are conveyed to the flight crew for insertion into the aircraft navigation system. The aircrew then flies the aircraft to the PADS-computed CARP and initiates payload release using standard C-130 and C-17 airdrop procedures.

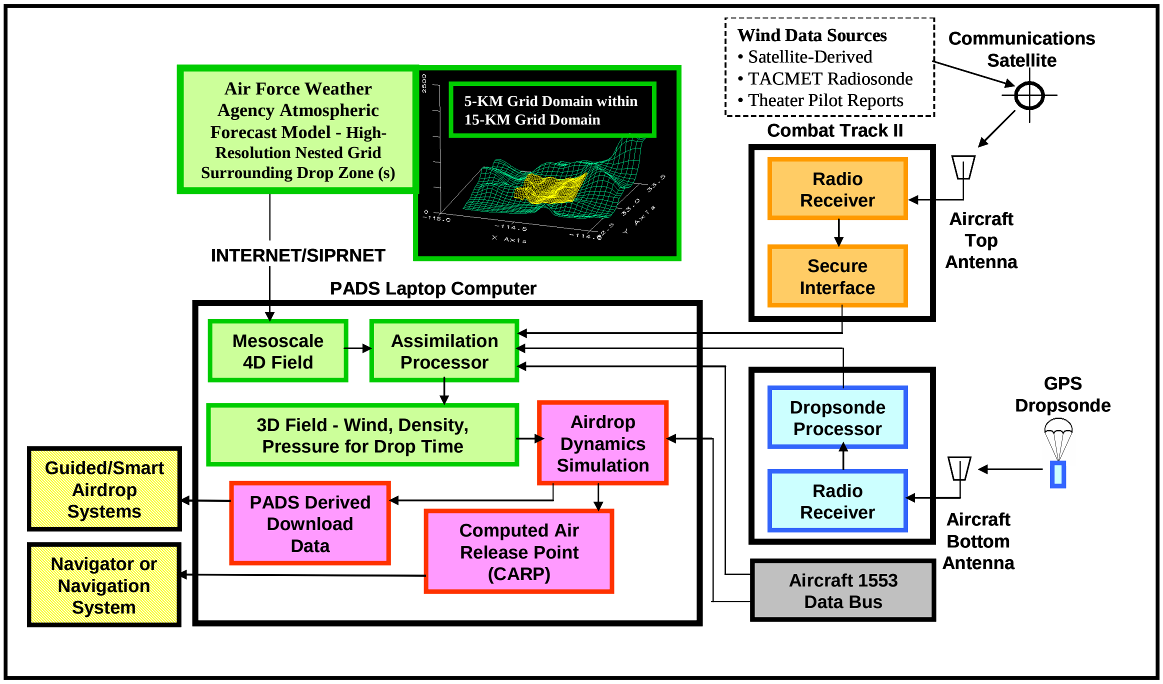

Figure 3. Connectivity and Data Flow of PAD Components

4. USER FEATURES

Graphical User Interfaces (GUIs) emulate the Air Force Portable Flight Planning System Combat Airdrop Planning System (PFPS CAPS); the operationally fielded standard. There are separate customized payload data entry pages for both C-130 and C-17 aircraft and a FalconView Graphical Map Interface (GMI) display to monitor the aircraft track near the drop zone and the overlay of ballistic parachute delivery accuracy footprints.

Figure 4 shows the top-level PADS GUI. Buttons on the left activate additional displays for aircraft, drop zone, payload, and weather data. Inputs are checked for proper entry, consistency, and limitations. Tabbed panels summarize user entered data, CARP calculations and en-route navigation processing. Engineering-related display pages are also available.

The Weather GUI is shown at Figure 5. This feature handles data acquisition, data assimilation, and wind file production. The Weather GUI generates a high-resolution 3-D data field—winds, pressure, density—surrounding the intended point of impact at the planned drop time using the tailored LAPS algorithm. The resulting data replaces the single forecast ballistic wind, pressure altitude, and temperature-at-altitude used in current Air Force CARP calculation procedures.

Figure 4. Top Level PADS GUI

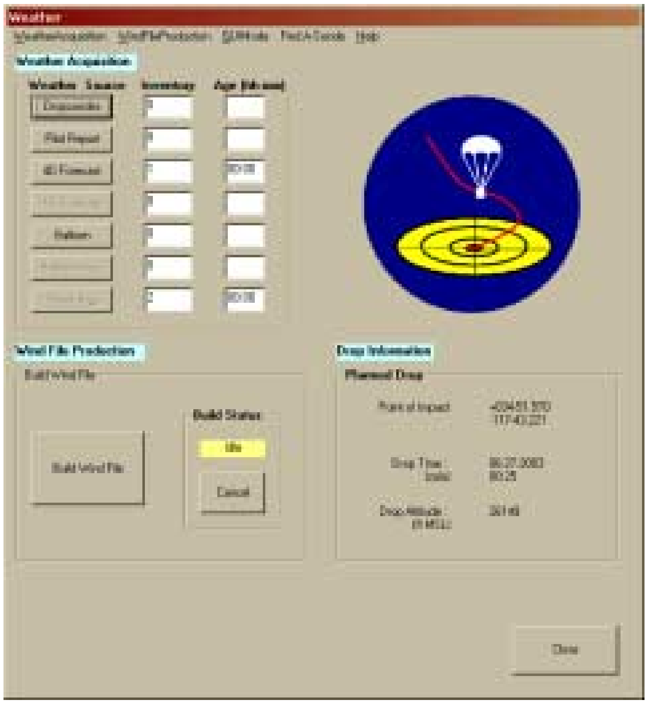

Figure 5. Weather GUI

5. PRELIMINARY COMPONENT ERROR ANALYSIS

Sample results of C-130 payload drops from approximately 10,000 and 15,000 feet above ground level during PADS tests at YPG, Arizona are shown in Figure 6.

Using PADS YPG flight test results, PSI conducted a preliminary component error analysis to estimate overall ballistic airdrop error contributions. Twenty-seven airdrops from C-130 aircraft were evaluated in the study for payload releases from approximately 10,000 to 25,000 feet above ground level. All ballistic drops used 26-foot Ring Slot parachutes.

Three principal error components were examined in the analysis.

- Green Light position error
- Payload release error
- Payload trajectory error

The first error component could be the result of navigation or Green Light timing errors. Green Light is the point in time/space when the payload launch process is initiated. The second component, payload release errors, could be due to unrecognized wind components at aircraft altitude, errors in the model of payload roll-out versus flight station, or variations in aircraft airspeed or heading. The payload trajectory component included payload exit to stabilization point (forward throw and altitude loss effects) and stabilization point to ground impact. Errors related to the first category include model uncertainty for canopy deployment and payload deceleration as well as errors in the assumed aircraft altitude (from pressure profile and altimeter effects). Errors in the stabilization point to ground impact segment include errors in payload weight, errors in canopy drag coefficient and/or errors in the 3D wind and density field.

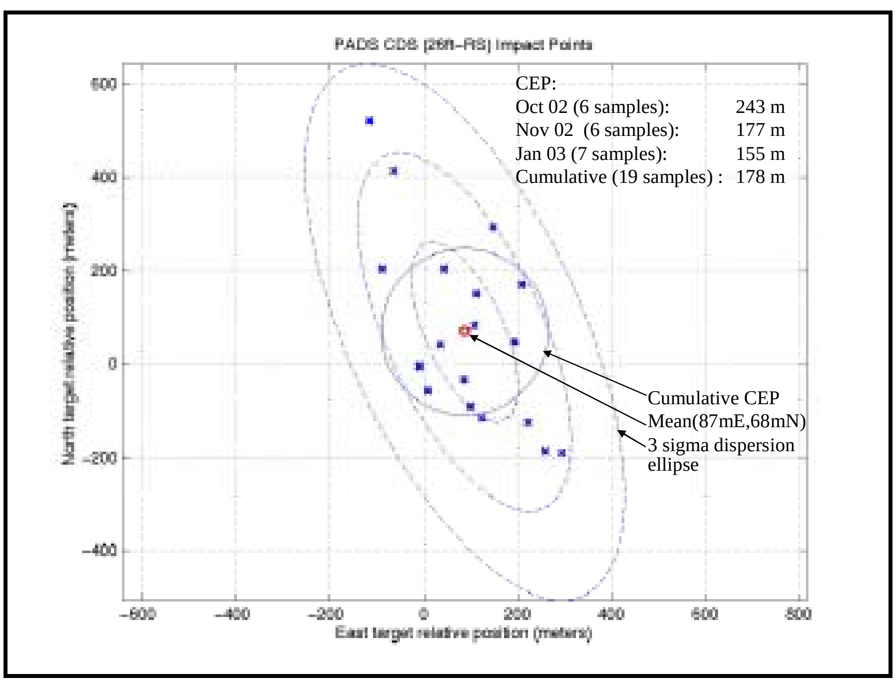

Figure 6. Landing Errors of Ballistic 26 ft RS Airdrops Performed Using PADS-Derived CARPs

5.1. COMPONENT ERROR ANALYSIS PROCESS

Comparisons were made between actual flight paths derived from YPG ground-based radar tracking data and PADS simulations for a CARP determination based on the Planned Point-of-Impact. Green Light and exit conditions were derived from aircraft 1553 data bus and camera data. Assumptions were for flat terrain (no lateral variation in the wind field) and the same relative navigation error applied to improved CARP simulations. Wind data assimilation for the analysis applied LAPS with AFWA forecast fields and dropsonde data recorded with each test flight. National Imagery and Mapping Agency (NIMA) 1-kilometer resolution topography data were used, but 1553 data-bus-derived winds at altitude were not assimilated. Another important point is that PADS ballistic airdrop models have consistently been improved based on actual airdrop flight test dynamics data. PADS simulations based on updated models reduced expected errors by over 500 meters from versions in place at the time of the actual flights.

Figures 7, 8, 9 and 10 graphically depict the component error analysis process for a specific airdrop case.

Figure 7 shows the actual (radar) trajectory (red) of the payload from when it is aboard the aircraft from Actual Release Point (ARP_0) through Actual Exit Point (E_1) and then through canopy opening to stabilization point (not shown) and then to Actual Impact Point (IP_0). The distance from IP_0 to the intended Point of Impact (PI) is the complete system error ("2"). The dashed line is the simulated trajectory from the PI to the Original $CARP_0$ using the version of PADS used for the airdrop mission. The distance from ARP_0 to $CARP_0$ is the Green Light position error ("1"). The solid black line depicts the simulated trajectory using a later, improved version of PADS, for the same PI. The simulation used a 3D field based on LAPS assimilation of AFWA forecast fields and the dropsonde data profile.

Figure 8 shows the hypothetical actual trajectory (red) if a later improved version of PADS had been used to determine the CARP used by the aircrew. Graphically, the trajectory is translated such that ARP_1 bears the same relationship to the new $CARP_1$ as ARP_0 did to $CARP_0$. The hypothetical complete system error is depicted by "3".

Figure 9 shows the hypothetical actual trajectory (red) if the Green Light Position Error was zero (i.e., perfect execution of the CARP). With no Green Light Position Error, the distance ("4") between the Exit Points is the Payload Release Error.

Figure 10 shows the hypothetical actual trajectory (red) if the Payload Trajectory Error was zero. The distance ("5) between the hypothetical IP_3 and the PI is the Payload Trajectory Error.

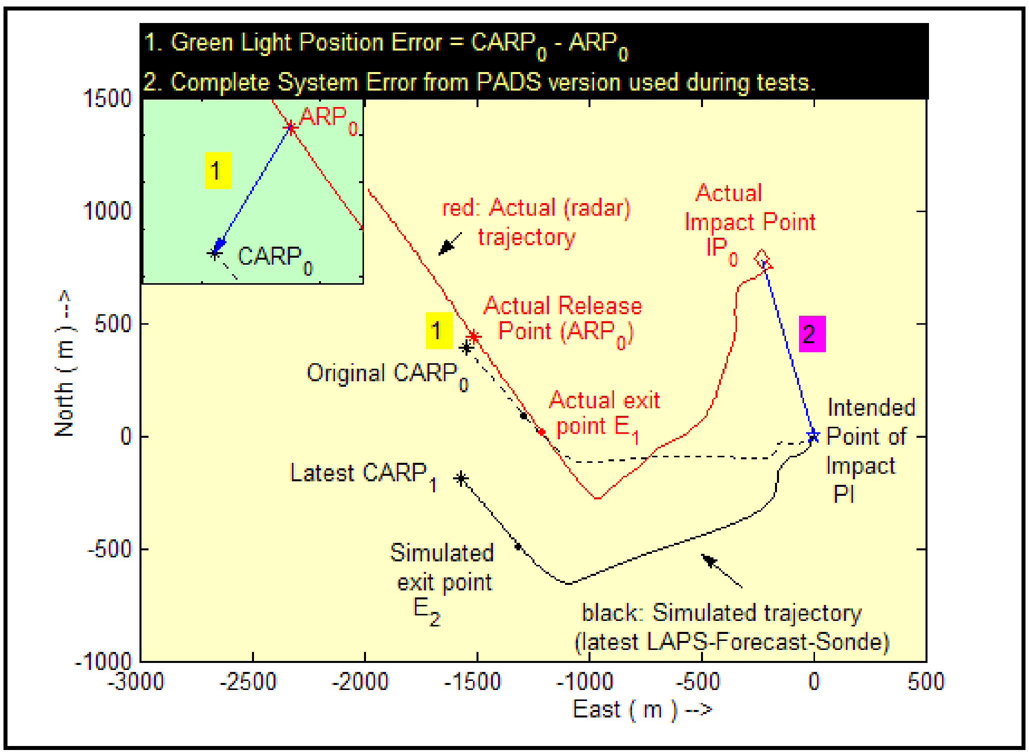

Figure 7. Actual and Simulated Trajectories

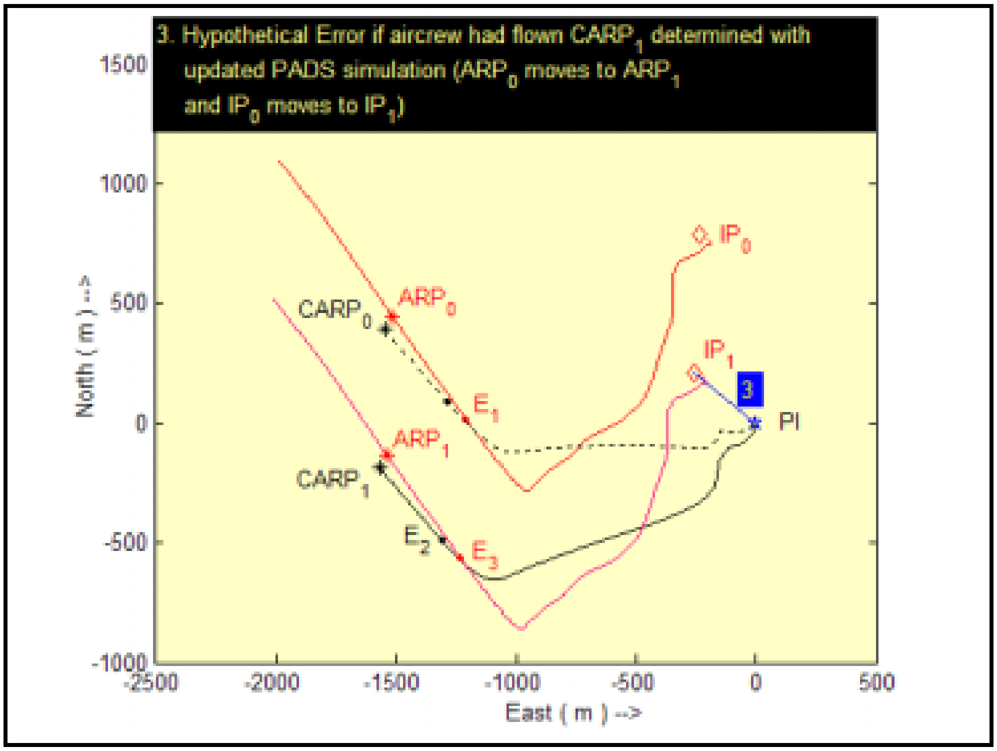

Figure 8. Hypothetical Actual Trajectory

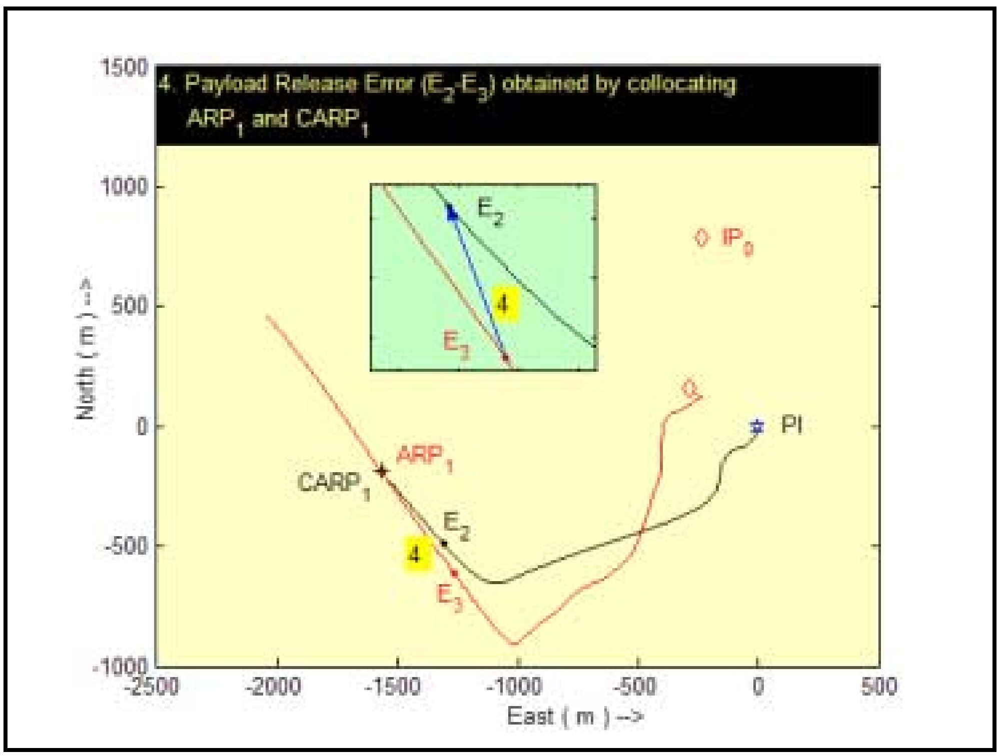

Figure 9. Hypothetical Actual Trajectory with No Green Light Position Error

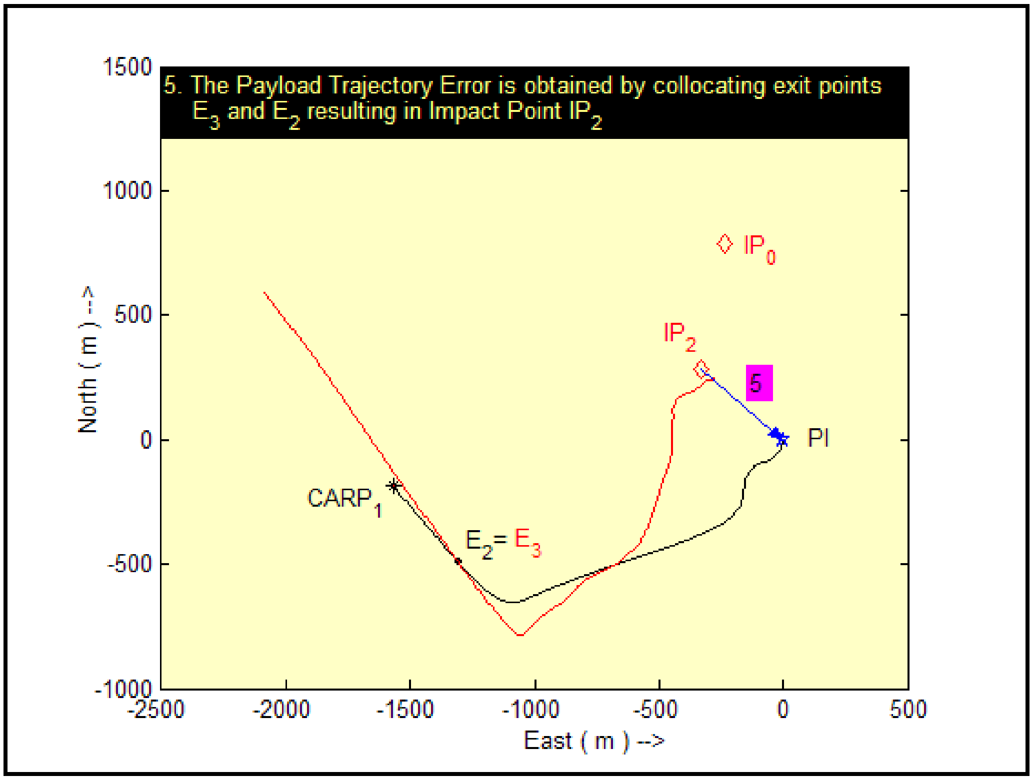

Figure 10. Hypothetical Actual Trajectory with No Payload Release Error

5.2. ESTIMATED ERROR CONTRIBUTIONS

The overall airdrop error contributions for the three major components analyzed are shown in Figure 11. Airdrop altitudes ranged from approximately 10,000 feet to 25,000 feet above ground level and payload weights ranged from near 500 pounds to 2,000 pounds. Relative scalar percentages of the total error are shown for each component. The errors of the three major components are vector errors and are assumed to be statistically independent of each other. On an airdrop mission, a component vector error can offset other vector errors of the airdrop system; consequently the sum of the independent scalar errors is to more than 100%.

Error Component	* Average Error (m)	Scalar % of Total Error	Error Standard Deviation (m)
Complete System	321	100	223
Green Light Position	134	42	85
Payload Release	104	32	120
Payload Trajectory	264	82	208

*** Adjusted to CARP from updated PADS simulation**

- Number of Airdrops: 27
- Altitudes:
  - 9,863 ft – 15,315 ft AGL: 13
  - 17,427 ft – 24,772 ft AGL: 14
- Payload Weights:
  - 550 lbs – 832 lbs: 7
  - 1,095 lbs – 1,840 lbs: 10
  - 2,070 lbs – 2,203 lbs: 10

Figure 11. Overall Component Errors

Figures 12 and 13 show the contribution of the three error components when the samples are grouped into a medium airdrop altitude band (approximately 10,000 feet to 15,000 feet) and high airdrop altitude band (approximately 18,000 feet to 25,000 feet).

Error Component	* Average Error (m)	Scalar % of Total Error	Error Standard Deviation (m)
Complete system	377	100	257
Green Light Position	175	46	93
Payload Release	71	19	74
Payload Trajectory	317	84	244

*** Adjusted to CARP from updated PADS simulation**

- Number of Airdrops: 14
- Altitudes:
  - 17,427 ft – 24,772 ft AGL
- Payload Weights:
  - 550 lbs – 833 lbs: 6
  - 1,583 lbs – 1,840 lbs: 5
  - 2,070 lbs – 2,130 lbs: 3

Figure 12. High Airdrop Altitude Band

As would be expected, the adjusted Complete System Payload Trajectory Errors are significantly greater for higher altitudes (greater time of exposure to wind errors during descent). The relationship between the other error components in the medium and high altitude bands is also significant, but the cause is not readily obvious. Faster ground speeds at higher altitudes (more sensitive to timing errors) and high altitude flight control at slow airdrop speeds (135 knots Indicated Airspeed) may contribute to the Green

Light Position Error differences. Payload Release Error differences requires further analysis. In both airdrop altitude bands, Payload Trajectory Error provided a much greater error contribution than the other two components. Improvements in wind field analysis stands to provide the greatest avenue of accuracy improvement for PADS.

Error Component	* Average Error (m)	Scalar % of Total Error	Error Standard Deviation (m)
Complete system	260	100	159
Green Light Position	86	33	38
Payload Release	142	55	149
Payload Trajectory	207	80	136

*** Adjusted to CARP from updated PADS simulation**

- Number of Airdrops: 13
- Altitudes:
  9,863 ft – 15,315 ft AGL
- Payload Weights:
  550 lbs: 1
  1,095 lbs – 1,585 lbs: 5
  2,070 lbs – 2,203 lbs: 7

Figure 13. High Airdrop Altitude Band

6.0 SUMMARY

PADS achieved a major milestone at the C-17 operational utility evaluation in September 2003. Flight test data collected over the life of the program enabled identification and resolution of some LAPS assimiliation and mission planning implementation errors. These enhancements enabled progressive improvement in PADS airdrop performance. In addition to improving the atmospheric model, test data from both C-130 and C-17 aircraft enabled adjustments to previously documented exit time, stabilization, and descent rate models. PADS is ready for fielding as an initial operational capability. It provides an ability to plan and deliver high altitude ballistic parachute payloads with vastly improved accuracy. Planned system enhancements will further improve the LAPS assimilation algorithm, make the software and GUI more robust, and reduce the size and weight of the hardware.

ACKNOWLEDGEMENTS

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