Precision Airdrop System SPADES

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ABSTRACT

In the Netherlands a cargo precision delivery system for 100 - 1000 kg payloads utilising ram air parachutes for different weight classes has been developed by Dutch Space in partnership with the National Aerospace Laboratory NLR. The system is based on 'Global Positioning System' (GPS) position information to fly autonomously towards a delivery point.

In the past the Smart Parafoil Autonomous Delivery System (SPADES) has already shown the delivery of payloads at programmed ground-locations with an accuracy of much better than 100 m (CEP) with the G9-Galaxy (160 kg), the tandem-parafoil PBO (250kg) of Aerazur, as well as the Firefly parafoil (500-1000 kg) of Para-Flite.

Presently the design of an operational version is in full progress to handle payloads from 100-1000 kg with one control unit. This version shall be available by end of 2006. In order to cover this payload-range basically three types of parafoils shall be required: 100-250 kg, 250-500 kg and 500-1000 kg.

For the execution of a mission the on-board processor does not require any information on the wind profile. Rough wind information, as is used for para jumps, is necessary for the mission planning to estimate the air-volume in which the CARP (release point) can be selected.

Using parafoils with a glide ratio of 3 in wind-still conditions, stand-off ranges in the order of 10-20 km can be obtained in case the system is dropped at 25,000 ft altitude. Adding the advantage of wind-drift the effective stand-off could increase up to 50 km or even more.

In this contribution to the AVT-133 conference the SPADES system is an example of a precision airdrop system that autonomously delivers payloads with high accuracy at a desired ground location.

1.0 INTRODUCTION

In the near future precision airdrop shall be an important logistic means for safe and accurate delivery of supplies in hazardous areas. The use of ram-air parachutes enables safe releases at high altitude and significant stand-off. Based on GPS-navigation at present accuracies better than 100 m CEP (*Circular Error Probability*) have been achieved.

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Figure 1 (left) Release of 500 kg payload with SPADES using the Firefly parafoil of Para-Flite

Figure 2 (right) Example of SPADES precision landings.

The Armed Forces of several countries already recognise the advantageous capabilities to re-supply forward troops or isolated units. Especially the property of high-altitude drop, up to 30,000 ft, enables the possibility to stay away from local threats. Also the option to drop materials at a stand-off distance of more than 10 km allows drops from positions that do not expose the exact ground locations of the troops on the ground. Application of ram-air parachute systems is useful since autopilot algorithms of autonomously guided flight-units are able to compensate for local winds during flight and steer accurately towards the programmed destination.

2.0 THE SPADES AIRDROP SYSTEM

During the development of the SPADES system [1,2 and 3], a co-operation between Dutch Space and the National Aerospace Laboratory, NLR in the Netherlands, it was shown in a variety of demonstration flights that it is technically feasible to achieve such precision landings. Especially the unique SPADES feature of "no-need-to-know the wind profile in detail" is an operational advantage. The required accuracy of the wind prediction is similar to the information that paras need for the determination of the location where to jump from the plane. The same type of information is needed for the SPADES mission planner only. The system itself does not obtain or need any information input on the wind profile. The system will assess this wind profile on-board during the flight. The only pre-flight information that is required as input for the guidance system are the co-ordinates of the desired Surface Delivery Point, sometimes also indicated as IP (Impact Point).

The development of the SPADES precision airdrop system started with a small payload version that was selected for gaining experience with autonomous control of such systems. Supported by the Royal Netherlands Army (RNLA) and in co-operation with the Royal Netherlands Air Force (RNLAF) a 160 kg version based on the G9-Galaxy has been developed and demonstrated. As a first step for extension of the payload-mass a tandem-parachute PBO (50 m^2) was used to deliver up to 250 kg payload.

In the last year the SPADES system has extended its capability also for larger parafoils (Firefly of Para-Flite with 95 m^2) that are suitable for payloads from 500 kg up to 1000 kg. So, in the range from 100 kg-1000 kg, experience has been gained in applying different types of parafoils, which are suitable for different payload classes.

During the development a laptop-based ground station has been applied to monitor the system in-flight.

From this ground station it is possible to override the on-board guidance system and to remotely control the system. In general this option has been worked-out for special safety reasons related to development-tests and demonstration flights, but may also be useful for training purposes when the system is operational.

Figure 3 (left) Two SPADES systems(250 kg payload) ready for loading into aircraft.

Figure 4 (right) SPADES with Firefly parafoil and 500 kg payload.

After the development-phase with a demonstrator configuration, presently the design of a fully operational control-unit is in full progress. Based on the experience gained during this development phase and general user-requirements, the design of the new configuration is based on an ‘easy-to-use’ philosophy. This means that this new configuration of the control unit, for the delivery of 100 kg-1000 kg payload shall be user-friendly in operation and handling. It has minimum weight and is made up in two parts of less than 25 kg.

The complete precision airdrop unit can be subdivided into three main parts:

- Parafoil
- AGU (Aerial Guidance Unit), which is a control-unit with on-board instrumentation and computer (running the Guidance, Navigation and Control software)
- Payload container

In order to obtain an easy-rigging procedure it is required that the rigging of the payload can be prepared separately from the AGU and the parafoil. After the AGU with parafoil is prepared, it can be strapped to the payload. The parafoil is a soft pack mounted on top of the AGU.

As indicated before, the modular SPADES AGU consists of two parts, 1) the control-box with instrumentation and 2) a structural frame for transfer of the forces from the parafoil to the payload. Separating the mechanical structure from the control box makes the control-box a light-weight unit of less than 25 kg that can be used for all parachute-types in the payload-range 100-1000 kg. As a result of lessons learned during demonstrations, the design of the control-unit configuration is such that when the AGU is already fully rigged, it is still possible to exchange the batteries, if necessary.

The payload can be rigged by standard containers like A-7 for the payloads until 225 kg or A-22 for payloads up to 1000 kg. In case of the latter extra straps are required to mount the payload to the frame of the AGU.

For the recovery of the control-unit after a field-landing, it is especially useful that the light-weight control-unit can easily be separated from the frame. In this way this box can also be recovered hand-carried when no other means of transportation is available.

The concept of the new modular configuration of the SPADES control unit is presented in Figure 5 below.

Figure 5 The new operational SPADES guidance-unit configuration.

Another aspect of airdrop systems is EMC. Just like the previous development configuration, this new configuration will also be compliant to MIL-requirements with respect to EMC. On the present development configuration several radiation tests have successfully been performed according MIL-STD-461E. In consequence of this qualification the system-configuration could already be dropped from a wide range of aircraft types, including C130 Hercules, C17 Globemaster, Fairchild C123, Transall C160, Casa CN-235 and SkyVan.

The SPADES system operates best if GPS signals are received in the cargo-bay before release. A GPS signal repeater is therefore recommended. In some cases a GPS-repeater is installed as standard equipment in the cargo-bay of the aircraft. When no GPS-repeater is standard available, there are rather simple solutions on hand. With a limited impact on the aircraft equipment, the on-board GPS-antenna signal can be tapped or a stand-alone solution with a GPS-antenna at a suitable window-location can be installed.

3.0 PERFORMANCE

The new operational SPADES configuration shall have all features available that have been tested with the development model. The main features with respect to flight-performance are as follows:

- The system can be dropped at altitudes > 30,000 ft.
- The system can be dropped from a large horizontal stand-off distance (up to 20 km in still air with a glide ratio >3 from 25,000 ft altitude) with respect to the delivery point on the ground.
- The system lands close to the target point <100 m CEP
- The system can be dropped inside a wide air-volume without decreasing landing-accuracy capability.
- A soft landing is carried out into the wind and with a flare manoeuvre.
- The system can fly under different meteorological conditions.
- The system is flexible to fly with a range of parafoil types and suspension weights.

A *drop altitude* of 30.000 ft is generally sufficient to cover most custom requirements. Nevertheless, the control-unit shall be designed for drops up to 35,000 ft. Currently the system is tested for environmental conditions encountered in the atmosphere up to this altitude. In demonstration tests the flight-altitudes are mainly limited due to the flight-time or safety limitations. During a drop-test at the Yuma Proving Ground the SPADES system has been dropped from 27,000 feet altitude.

The maximum *stand-off*, i.e. the maximum horizontal distance between the release point and the landing point, is dependent on the release altitude and the wind. In no-wind conditions the maximum stand-off of a SPADES system released at 30,000 feet can be >20 km. With a wind profile found commonly in the atmosphere this maximum can even be enlarged up to 50 km. However, due to limitations at test sites for release altitude or horizontal distance of the release point, these large stand-off distances have not been tested nor demonstrated, yet. The maximum stand-off capability for a SPADES system has been demonstrated at the PACD 2006 in France. In a drop from 6,000 ft altitude the horizontal distance from the release point from the landing point was 6.7 km away. The landing accuracy for this flight was 28 m under the prevailing wind conditions of ±10 knots.

The *accuracy* of the distances between targets and actual landing points during all demonstrations flights is 72 m CEP (Circular Error Probability). This value includes demonstration-values of a system in an earlier development version. It is expected that the system with the current status is even more accurate.

Figure 6 (left) SPADES in-flight with 250 kg payload.

Figure 7 (right) SPADES flight demonstration in The Netherlands.

A *large air-volume* can be used *to release* a system for one Surface Delivery Point. In demonstration-flights at Yuma Proving Ground and Biscarosse (France) it has already been shown that it is possible to drop two systems with a time interval of more than 30 seconds at an altitude of 10,000 ft while heading for the same Surface Delivery Point. At an aircraft-velocity of 130 KIAS the CARPs of both systems are more than 2 km away from each other. In these demonstrations this feature has been shown by using two systems in one pass of the aircraft. Alternatively, it would have been possible to drop also 4-5 other units in the same time period.

To carry-out a *soft landing* the on-board processor calculates the wind direction based on the available sensor-information and lands into the wind. The flare manoeuvre is initiated just before landing. This landing-procedure limits the landing shock on the payload. Of course the magnitude of this shock highly depends on the roughness of the ground surface and the wind variations of the actual ground-wind.

The *meteorological conditions* for SPADES drops are less restrictive than for manned flights. Especially for strong winds at the ground. The limit for a manned flight at strong wind is that, when flying into the wind, at least the velocity with respect to the ground should be forward. In this way the para can be prepared for landing. In case of the unmanned SPADES system there is no problem in backward landing. So, for cargo drops, the wind-velocity limitations can be less restrictive than for manned flights. Furthermore, sight-limitations in clouds, rain, fog or darkness are non-existing. In the past SPADES has already been dropped in/above clouds as well as in rainy conditions.

With respect to *parafoil types and suspension weight* the SPADES configuration has flown with several parafoil types in the payload-range 100 – 1000 kg. Suspension-weights between 90 and 500 kg have been successfully applied in drop-tests. In addition, the new operational control-unit is designed for 1000 kg payload. Tests with this payload shall be combined with the implementation of the new configuration. Since the characteristics of the applied parafoils are part of the control data-base the influence of variable suspension weight under each parafoil are easily adapted. This makes the system flexible for different customer requirements.

The features mentioned above have been developed, tested and demonstrated. The SPADES system was shown in several demonstrations. These were held for international forums in the Netherlands, organised on behalf of the Royal Netherlands Army, and at international events, including the PATCAD-2003 (Precision Airdrop Technology Conference And Demonstration) and PATCAD-2005, both organised by Natick Soldier Center of the US-Army at the Yuma Proving Ground (AZ), and the PACD-2006 (Precision Airdrop Capability Demonstration) in Biscarosse, organised by the French Army (DGA). The demonstrations were performed with the SPADES configuration using the (34 m^2) G9-Galaxy parafoil, P533 (PBO) tandem parafoil (50 m^2) of Aerazur and the Firefly parafoil (95 m^2) of Para-Flite

4.0 WIND INFORMATION AND MISSIONPLANNING

For the mission planning wind information is required to determine the CARP (Calculated Air Release Point). An example of used wind information obtained from the meteo early in the morning (7.00 pm) on a day of testing is given in Table 1 below. Although there was a list available with an interval of 100 ft altitude, for the SPADES mission planner the list was reduced to at least an interval of 1,000 ft altitude.

Pre-flight wind information Wind-speeds and -directions		
Altitude [ft]	**Speed [kt]**	**Direction [deg]**
1290 (Surface)	Var	Var
2000	19.2	20
3000	19.4	22
4000	12.1	5
5000	9.5	357
6000	8.8	9
7000	11.0	26
8000	8.2	14
9000	10.4	19
10000	11.2	360

Table 1 Example of wind profile information.

Unless the wind would be changing drastically that day, this data was used to define the CARP of the drop around noon that day. Also early in the morning the co-ordinates of the specified landing point were already pre-programmed into the system. With this information the system was fully prepared for the drop.

The wind profile is used for the mission planner only to determine the CARP, but is not transmitted to the on-board processor of the SPADES flight-configuration. During the descent the processor shall estimate the wind-velocity in-flight based on its sensor-information. Based on this data the processor will guide the system towards the delivery point by compensating for the wind.

In order to show that the wind-information, used by the SPADES on-board processor, is basically correct, the data is compared with data from PADS wind-sondes (manufactured by PSI). During one of the international demonstrations it appeared that two PADS-dropsondes were dropped within the same time-frame that the SPADES system was dropped. One sonde before, and one sonde after the SPADES drop. Later-on, during the post-flight evaluation of the demonstration-results, the sonde-data has been made available by PSI. The results of the processed data from these sondes are given as curves with symbols in Figure 8, the wind-velocity [m/s] in the left plot and the wind-direction [deg] in the right-hand plot as function of the altitude (vertical) in meters.

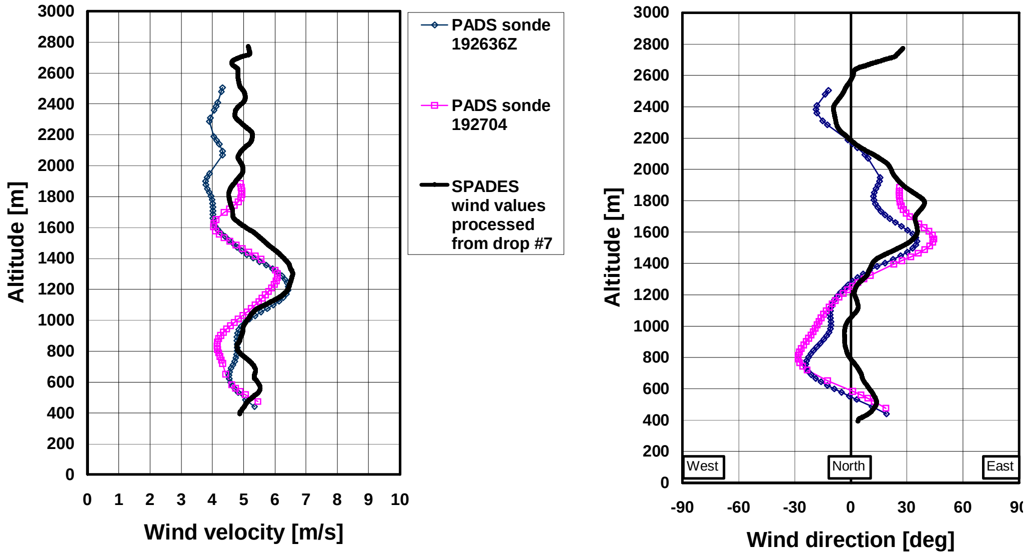

Figure 8 SPADES wind profile compared with sonde-values.

Now it was now possible to compare this sonde-data with the wind-data derived by the on-board processor. For a realistic comparison, the flight-data of the SPADES have been filtered post-flight, as well as the dropsonde-data was. The result-curves of wind-velocity and the wind-direction derived from the SPADES flight data is also shown in Figure 8. Both curves are indicated as (black) solid line.

From this comparison it can be concluded that the basic wind profile derived from the SPADES flight-data is similar to the data obtained from the wind-sondes. Remind that the curves shall not be fully the same, due to the fact that the sondes have a ballistic trajectory and the parafoils have a glide-trajectory and, as such, are not measuring data at 'exactly' the same location nor time.

Note, that although rough information is sufficient to carry out a mission planning for a SPADES-drop, it will always be necessary to have most accurate wind-information when the CARP is selected close to the edges of the calculated air-volume of the Release Zone Area.

5.0 CONCLUSION

In the near future Precision Airdrop Systems shall be a logistic means for accurate aerial delivery of supplies. As such SPADES is a good example of these types of systems.

After an effective development process with demonstrator systems for 250 and 500 kg, the development of a new operational SPADES control-unit is in full process. With an accuracy of <100 m CEP, this control unit shall be applicable for the complete payload-range of 100-1000 kg. For this range basically three types of parachutes are appropriate 100-250 kg, 250-500 kg and 500-1000 kg. In addition the modular design of the AGU is built-up in two parts of max 25 kg each, so that it can easily be man-carried recovered from a field-landing.

Wind information is only required for the mission planner. This information is not transmitted to the on-board processor. The processor shall correct for wind-effects, determining the wind-information in-flight. In a special case, during a demonstration, PADS-sondes of PSI were dropped just before and after a SPADES flight. In this way reference wind-information was available and could be compared with the SPADES generated data in a post-flight evaluation. Both wind profiles appeared to show a good similarity.

In conclusion, the new operational SPADES will be able to fulfil the short term requirements that are currently set by international Defence Forces.

6.0 REFERENCES

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SYMPOSIA DISCUSSION – PAPER NO: 5

Author's Name: J.W. Wegereef, H.W. Jentink

Discussor's Name: L. Ruiz-Calavera

Question:
In your paper you mention possible civil applications of SPADES. Could you give some examples and explain how they are different from "normal" military operation?

Author's Response:
Humanitarian aid is the civil application we foresee. For instance you can deliver boats to areas with bad access after a flooding or you can deliver medicines. The application is very similar to military operations. Probably mostly military transport aircraft will deliver the goods, although C130S, and of course also smaller transport aircraft, are also operated by civilians.