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Field tests on an integrated Differential GPS navigation and spray monitoring system for aerial Desert Locust control operations

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Emergency Prevention System (EMPRES) - Desert Locust Component

Project GCP/INT/651/NOR

Field tests on an integrated Differential GPS navigation and spray monitoring system for aerial Desert Locust control operations

Sudan 25 March - 8 April 1998

by

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Summary

Incorrect and inaccurate application of pesticides have for many years been a problem in Desert Locust control. We have investigated whether a computerised track guidance device linked to a Differential Global Positioning System (DGPS) combined with a spray monitoring system can help to overcome these problems. Trials were done in a natural Desert Locust environment at the Red Sea coast of Sudan in March and April 1998.

The system tested was a AGS III from UTS Navigation Systems, combined with a Micronair Spray Monitoring System, and installed in a fixed wing aircraft. The system was compared with conventional navigation techniques and gave excellent performance in terms of avoiding over and under exposure of target areas. Almost no deviations from straight lines and from target boundaries were recorded with DGPS navigation, whereas the conventional technique resulted in poor coverage of the target area with some areas being sprayed repeatedly as well as areas outside the target being treated. The system allowed for accurate exclusion of areas that should not be sprayed, like villages and water bodies. Barrier spraying was extremely precise. Spraying within polygonal areas was just as easy as rectangular areas, so was spraying of several polygonal areas within a larger area. Coordinates for areas to be sprayed/not sprayed can be entered before takeoff, during flying or recorded by the pilot himself by flying once around the area before treatment starts. After treatment, the system gives printouts of the area, flight track spacing, area treated, amount of pesticide used, etc. All coordinates loaded into the aircraft computer can be exported as an Arc Info file for inclusion into the FAO Desert Locust data base (SWARMS) or other data bases. The spray monitoring system recorded among others total flow rate (flow rate on each atomiser is also possible) and rotation speed on each atomiser.

We see several additional advantages of this system for Desert Locust control. A substantial number of ground personnel would be freed for supporting aerial control operations (e.g. flag-men). These could concentrate on prospecting and coordinate the delimitation of swarms. There will now be full control on what areas are treated and how effectively they are treated. Additional cost reductions are possible through less use of pesticides. There is no need to overdose in order to compensate for inaccurate calibration and application.

There is still room for further improvements. A major factor of variability is flight altitude, which is not well recorded with the DGPS. We have demonstrated that small variations in altitude can give very large deviations in pesticide droplet distribution on the ground. Time lags between "spray ON/OFF" and actual emission of the pesticide is not sufficiently controlled, making exclusion of small vulnerable areas difficult. Most importantly: even with very precise DGPS navigation and spray monitoring, the air turbulence, ground vegetation, and other factors can still result in large variations in ground droplet distribution.

We recommend that FAO requires all companies contracted for aerial locust control operations to have an integrated navigation and spray recording system installed. The system should preferably have an automatic connection between spray ON/OFF and the pre-loaded coordinates. This enables the pilot to concentrate on flying only. Further it should have a print out facility of areas treated and flight tracks, export facility to a GIS system (preferably Arc Info), flow rate recording and rotation speed recording of atomisers, preferably on each atomiser. A switching facility from GPS to GLONASS can be extremely important in some parts of the Sahara, where satellite differential correction beams are not properly received.

Foreword

This report describe results of the activity 6.3 "Evaluation of Differential GPS for improving aerial spraying precision" in the FAO project GCP/INT/651/NOR "EMPRES, Improving pesticide application techniques for Desert Locust Control".

As Team Leader for the mission, I would like to thank Dr. Wassila Goudora, Director of the General Plant Protection Directorate in Sudan for inviting us to do our trials in Sudan, and to Dr. Clive C.H. Elliott, Senior Officer, the Locust Group, AGPP/FAO/Rome for initiating the study, selecting participants for the team and for invaluable support during the preparations of the study. I would like to thank Dr. Munir Butrous, because he, in addition to the scientific work, also had the burden of arranging and mastering all the formalities, the co-ordination of people arriving at different times from different places, for food and lodging etc. He arranged everything in an excellent manner, and no delays or missing parts were experienced during the study. I would like to thank the Plant Protection Directorate, Red Sea Coast Winter Campaign lead by Abdel Moneim Khidir for invaluable help during the field studies, and for their hospitality and help.

The companies Micronair Ltd. and UTS Navigation Systems supplied the technical equipment used in the trials free of charge. Their two representatives paid their own salaries and DSA. Apart from their valuable technical and scientific input to the study, we thank them for this financial support.

I thank all my colleagues for valuable theoretical, practical and social inputs. And a very special thanks to the pilot Binkowski Bogdan and the technician Tchorzewski Alexander for doing all the flying in such an experienced an excellent manner.

I thank Dr. Bernhard Zelazny at the Locust Group, AGPP/FAO/Rome for comments on the manuscript.

Oslo, 21.12.1998

Dr. Preben S. Ottesen
FAO Consultant, Team Leader

Terms of reference, Team Leader

Under the supervision of the Senior Officer: Locust and Other Migratory Pest Group, AGPP, and in close collaboration with the EMPRES National Professional Officer (Control) and the Sudanese authorities, the consultant will lead a team to investigate the usefulness of a differential Geographical Positioning System (GPS) linked to an aircraft pesticide spraying system as a technology for improving locust spraying. The investigation will be carried out in typical Desert Locust habitat around the Port Sudan/Tokar Delta area of the Sudan. It will examine any advantages that the system may have in respect of reducing pesticide usage for full cover treatments and evaluate the systems as a means of carrying out accurate barrier treatments. The consultant will prepare, in consultations with the other members of the team, trial designs for the different applications.

The consultant will be responsible for preparing a report on the trials and will arrange for contributions to the report to be made by the different participants as appropriate. The report will be prepared electronically and submitted to the FAO as an e-mail attachment.

Contents

Participants

EMPRES, Western Region
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Binkowski Bogdan, Pilot
Tchorzewski Alexander, Mechanic

Plant Protection Directorate, Red Sea Coast Winter Campaign
Abdel Moneim Khidir, Head of Campaign
Ibrahim Magzoub, Technician
Salah Abdel Atti, Technician
Ali Eisa, Driver
Yassir Ahmed Ali, Driver

Program

Date	Program	Flight hrs
25 March	Aircraft form El Hasaheisa to Suakin at the Red Sea coast	5:40
26 March	Calibration of spraying equipment, pilot training on ground	0:30
27 March	Calibration of spraying equipment, Assessment of swath width	0:20
28 March	2 x 1 km with GPS	0:30
29 March	2 x 1 km without and with GPS	0:48
30 March	2 x 1 km without and with GPS	0:48
31 March	Polygonal area with exclusions	1:17
1 April	Barrier spraying, swath width estimation according to flight altitude. Pentagonal area with co-ordinates input by over-flying	0:39
2 April	Droplet distribution with double over-flown and missing line put into the test. Aircraft from Suakin to El Hasaheisa	0:53 5:18
3 April	Discussions and analysis of data	
4 April	Discussions and analysis of data, report writing	
5 April	Travel Port Sudan – Khartoum	
6 April	Report writing	
7 April	Report writing	
8 April	Departure	
	Sum:	16:53

Expenditures in Sudan

	US$
Flying hours	12,706
Aviation gas	3,187
Fuel	287
DSA	1,985
Various	801
Total	18,966

Introduction

Incorrect and inaccurate application of pesticides have for many years been a problem in locust control. The incorrect and overuse of pesticides during ground operations has been connected to inappropriate equipment being used, lack of knowledge on the side of the operators (no or wrong calibration, inability to determine the correct sprayer speed, track spacing and flow rate, unfamiliarity with safety requirements), lack of equipment maintenance, lack of supervision (related to both technical and organisational aspects), as well as a desire to achieve an unnecessarily fast knock-down of the target.

These problems have in particular been associated with aerial spraying operations which require special skills and involve more complex operations. A problem, inherent in aerial operations, is the accurate positioning of the aircraft while spraying. During ULV operations, wind speed, temperature, flying height and other factors influence how far the pesticide drifts before reaching the ground. Considerable experience and skill is required to ensure that the pesticide reaches the target area and only the target area. Target blocks are sprayed in strips with some overlap of the strips. The overlap should not be too little or too much to avoid over and under-spraying some parts of the block. In order to achieve precise flying paths, large ground teams (flag men) are required who then can be exposed to the pesticide. Higher dosages are often used to compensate for errors in the swath spacing and for the other problems connected to aerial spraying.

New technology may help to overcome these problems. Computerised track guidance devices linked to a differential Global Positioning System (GPS) have recently become available and enable accurate navigation of spray tracks and target blocks without having to rely on flag men on the ground. Such a system can also be programmed to avoid sensitive areas inside the block to be sprayed, e.g. water bodies. GPS give co-ordinates ± 100 m. With Differential GPS (DGPS) the best systems give positions ± 2 m. The Russian free of cost GLONASS system gives positions ± 15 m, with no differential beam required. Software and hardware for guiding pilots in their track spacing have been used in agricultural environments for eight years. Improved systems are rapidly being developed. A problem with the differential reference beam being obstructed by mountains was solved four years ago by the reference beam being sent out from a satellite. On the side of calibrating the spraying equipment, digital control devices are now available for measuring pesticide flow rate and atomiser spinning speed for each single atomiser, providing precise data on dosage and droplet size distribution.

During previous years, the DGPS system has been used sporadically during Desert Locust control campaigns. The purpose of the present study was to systematically evaluate the usefulness of DGPS navigation integrated with a spray monitoring system for Desert Locust aerial control operations. Questions of interest were

- Is the benefit of DGPS navigation measurable, compared to conventional compass navigation and to other factors that influence droplet distribution, like wind and, temperature, flight speed and altitude, topography and ground vegetation?
- How can the use of DGPS increase the efficiency of control operations with respect to savings in time and personnel use?
- How can the use of DGPS help to exclude areas that should not receive chemicals, like villages, pastures, lakes, rivers, marshes, etc.
- How can better precision be used to do spot spraying of sub-swarms, instead of blanket treatment of large areas, in which locust targets are sparsely distributed?
- What are the economical costs and benefits of DGPS?
- How can DGPS be integrated in the registration and database storage of locust control data?

During the trials we used an integrated navigation/spray monitoring system by UTS Navigation Systems and Micronair Ltd. We are aware that other companies exist that deliver similar systems, and hope that the results will help to evaluate the usefulness of such systems in general. The studies have clarified the specific needs of such systems for locust control. Companies might find the results useful for future development, in case their system do not meet such requirements already.

The Red Sea area of Sudan was selected for the trials, because swarms and hopper bands were present in the area in early 1998. Unfortunately, they disappeared some weeks before the start of the trials. We therefore had to concentrate on methodological studies and analysis of pesticide droplet distribution. The latter simulated the impact on the locust populations.

Material and Methods

Study area

The study area was located 2.4 km and 300° W of the city Suakin at the Red Sea Coast in the province of Red Sea (Al Bahr Al Ahmar) in Sudan, at the co-ordinates 19°06'32''N, 37°16'53''E. Exact UTM co-ordinates of the various test plots can be supplied on request. The landscape was a coastal plane without elevated areas, but with some wadi depressions. It is classified as a dry savannah. Rain usually falls between November and January with an average annual rainfall of 100 - 200 mm. Dry years receive only 60 - 100 mm, while wet years receive 200 - 400 mm. The vegetation is dominated by the broad-leafed bush *Calotropis procera*, which reached an average height of 1 m and a coverage of 10 - 20 %, with the highest density in the wadies. A few trees of *Acacia tortilis* were found, reaching heights of 2 - 5 m, along with low bushes of *Prosopis glandulosa*, both with a coverage of < 5 %. At the time of the field study, all grass vegetation, mostly *Panicum turgidum*, was dry and not erect. Coverage was < 5%. The soil was a mosaic of dry gravel and sand. The wadies were sandy, while some slightly elevated ridges were composed of gravel with some dry grass vegetation only. Most of the area had a soil mixture of sand, gravel and pebbles.

The field trials were done between 26 March and 2 April 1998. From December 1997 to January 1998 there were large Desert Locust swarms and several hopper bands in the area. In February the infestations declined due to control operations and drying conditions, but some populations survived until mid March 100 km Southeast of the study area in the Tokar Delta.

Technical equipment

The spraying was performed by the Polish aviation company Sudana Pezetel, Khartoum, using a double decker Autonow AN-2 ST-AKZ fix wing aircraft. It was equipped with eight atomisers, i.e. four on each side, of the type AU5000 from Micronair Ltd, UK. Since no locusts were present in the area, we used old pesticide stocks expired in January 1995, with documented biological inactivity. It was Diazinon 90 ULV (900g/l) from Nippon Kayaku Co. Ltd., Japan.

The atomisers were calibrated to yield a total of 1 l/ha and a droplet size of 80 µm. An outline of the integrated navigation and spray monitoring system is shown in Fig. 1. Brief technical information on the various components will be given in the sections to follow. For more detailed information, the companies should be consulted. For our trials, the "Spray ON/OFF" button was not connected to the chemical pump. Therefore, the pilot did the spraying, while spraying data in the AGS III was recorded by a second person pressing a separate button.

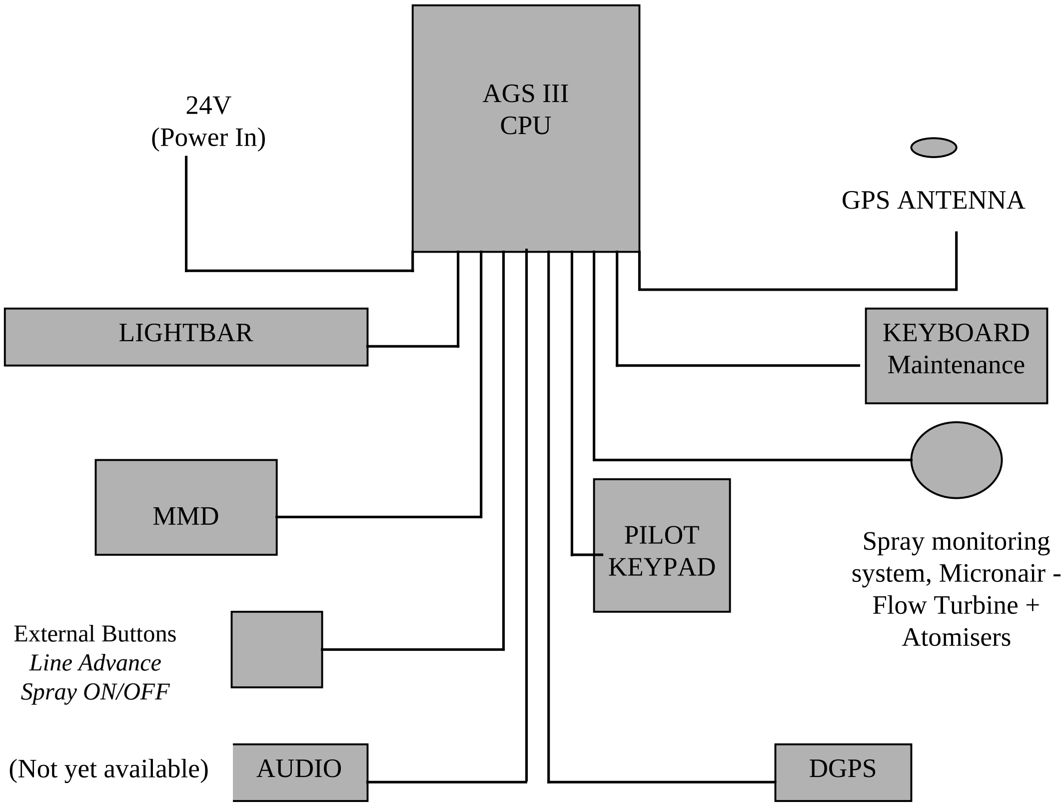


Fig. 1. *The components of the AGS III. CPU is the Central Processing Unit. The Lightbar is placed outside the cockpit in front of the pilot, and guides him in navigation. MMD is the Moving Map Display, where for instance tracks spacing, flight paths, areas, system configuration, etc, are seen. Keyboard is a portable computer for maintenance and analysis of the results. The Pilot Key Pad is the cockpit keyboard for controlling the system.*

GPS Track Guidance System

Manufacturer: UTS Navigation Systems (UTS)
Model: AGS III - (Airborne Guidance System)

System Components

- Main GPS processor unit with 12 channel 10 Hz GPS receiver, processor, power supply and interfaces.
- GPS antenna.
- LED light bar to provide track guidance and angle of intercept information for the pilot.
- Liquid crystal 'Moving Map Display' (MMD) for graphical display of the area sprayed, Horizontal Situation Indicator (HSI), system configuration etc.

- Buttons on MMD panel to access all commonly used system functions.
- Hand-held keypad for pre-flight entry of job data and system configuration and for post-flight downloading of data.
- Buttons for line advance and spray on/off (on a permanent installation this would normally be taken directly from the spray switch or lever).

Satellite Differential Correction

Manufacturer: Racal
Model: Landstar Mk III

System Components

- Raw GPS position data from the receiver in the system unit differentially corrected to compensate for inherent GPS system errors and deliberate degradation of position accuracy (selective availability). This is known as Differentially corrected GPS (DGPS).
- Differential correction provided by the Racal Landstar service. This transmits correction data from communication satellites which are independent of the GPS satellite constellation.
- DGPS for the trials programme provided by the Landstar European beam (other beams cover other areas).
- DGPS data for trials area derived from the Landstar reference station in Ankara, Turkey.
- DGPS data received with a Racal Landstar Mk III receiver with LPA7 antenna.

Note: *As an alternative to DGPS, the system may be fitted with a dual GPS/GLONASS receiver. This uses the US GPS and Russian GLONASS satellite constellations to give greater accuracy than would be possible with GPS only. The typical accuracy of this configuration is ±15 metres compared with ±2 metres for satellite DGPS.*

Spray Monitoring System

- Chemical flow rate from the aircraft measured by a Micronair flow-meter turbine with a range of 18 – 140 litres/minute (EX525, other ranges available for higher or lower flow rates).
- Atomiser rotational speed (RPM) measured by magnetic transducer sensing rotation of steel ‘finger plate’ bolted to atomiser hub.

- Flow-meter turbine and RPM transducer connected to Micronair Application Monitor with serial interface to GPS processor.

- Processing of raw data from Application Monitor carried out by GPS processor to give display of:
  - Chemical flow rate.
  - Chemical application rate (on basis of actual ground-speed and selected track spacing).
  - Volume of chemical used.
  - Volume of chemical remaining in tank (on basis of starting volume entered by pilot).
  - Spray time.
  - Area sprayed on basis of either track spacing (full coverage spray application) or swath width (barrier spraying).
  - Rotational speed of each of up to 10 atomisers.

Note: *An external Application Monitor was used for the trial installation to provide maximum flexibility with an unknown aircraft configuration. Future installations would use the UTS Mk IV GPS processor unit with the same functions integrated in the main system unit. A separate Application Monitor unit would not be required.*

Data Logging

- All spray mission data recorded within the GPS processor unit.

This includes:

- Aircraft position & time.
- Aircraft speed.
- Spray on/off.
- Chemical flow rate.
- Chemical application rate.
- Chemical used.
- Spray time.

- Data recording (logging) rate adjustable from 0.1 sec to 10 minutes.

- System will record data for a total of 500 flying hours at a logging rate of 0.5 sec.

- Recorded data can be replayed on the aircraft display transferred to an office or notebook PC by a portable hard disk drive (shuttle drive).

Spray Equipment

- Eight Micronair AU5000 rotary atomisers (four mounted on each wing).
  - Atomisers fitted with standard (EX1772) fan blades set to 35 degree angle.
  - Chemical flow to atomisers regulated by Micronair Variable Restrictor Units (VRUs) set to position #5.
- Chemical carried in standard AN-2 spray tank with maximum capacity of 1350 litres.
- Chemical delivered by standard AN-2 wind driven centrifugal pump with 3-bladed adjustable pitch fan.
- Chemical pressure adjusted by pilot operated electrically controlled by-pass valve.
- Chemical on/off valve operated by electro-pneumatic actuator controlled by switch in cockpit (chemical pressure and on/off controls are independent).

"UTS Office" Software

- Windows 95 based flight planning and reporting software is provided with the GPS system.
- The software provides the following job planning functions:
  - Pre-defined co-ordinates and outline of each spray block, including topographical features, exclusion areas etc. Multiple polygons can be defined.
  - Define job parameters (track spacing, application details, aircraft details, job details etc).
  - Import of map data in standard GIS formats.
- The software provides the following reporting functions:
  - View and print spray block layout, aircraft track, areas sprayed etc.
  - Edit detail on map of spray area (add annotations, additional features etc. Alteration of aircraft track or spray data is not possible).
  - Print job reports.
  - Archive job data on hard drive of PC, tape etc.
  - Export data in standard GIS formats - Arc Info / Genamap / DXF.

Note: *The Office Flight Planning software will run on any standard office or notebook PC capable of running Windows 95 applications.*

Droplet analysis

Droplets were collected on microscope glass slides of the size 76 x 26 mm. They were mounted vertically on 20 cm high metal sticks with a diameter of 2 mm, and oriented in upwind direction. The sticks were bent at the bottom to prevent twisting by the wind, and supported by small stones to maintain them in vertical position. The slides were numbered individually with a waterproof black marker pen (Fig. 2). Each slide position was marked with a circle in the sand, and was located by following the car wheel tracks. They were collected in microscope slide trays so that the surfaces with droplets were not disturbed. The droplet were counted at 10x magnification, using a hand lens. In daylight, and with a background of one light and one dark area beside each other, the droplets where shining against the background and easy to count. Three different areas of each slide was counted by placing a cardboard with 1, 0.5 or 0.25 cm^2 quadrate holes behind the slide, i.e. on the non-droplet side. The size of hole used depended on the droplet number. The numbers were expressed as droplets/cm^2. Counting was done by P. Ottesen and B. Johannessen. Since there was some doubt as to how small droplets should be counted, some were hardly visible, they both counted 18 slides. A correlation of $r^2 = 0.93$ and $p < 0.001$ was obtained, confirming that both counted in the same manner.

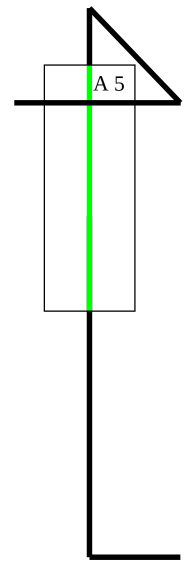


Figure 2. *Design of glass slide droplet collecting device.*

Oil sensitive paper from Ciba-Geigy. Switzerland, was used initially, but the black droplet markings faded out after two hours. Since counting was most convenient to do at the end of the day, glass slides were used only.

Area marking

Marking started by driving a baseline with a car, perpendicular to the wind direction. The other lines, (e.g. those simulating an area containing a locust swarm) were driven by the car, using compass and speedometer readings. The position of each corner was noted using a hand held GPS, so where sub-areas to be excluded from spraying.

Meteorological observations

Wind direction was measured with a mirror compass on small pieces of paper dropped in the air, wind speed with a ball anemometer with miles/hr readings, transferred to m/s with the conversion factor 0.447. During spraying, measurements were taken every 30 s, and the average calculated. Temperature and relative humidity was measured electrically, with the %RH given at ± 4%.

Field trials

Straight line flying and swath width assessment

Purpose

Conducting a first, simple test with the DGPS navigation. The swath width was assessed in order to be able to interpret the droplet distribution data in subsequent tests. On the same flight, the flow-rate was calibrated by spraying for a specific amount of time, and by post-flight registration of pesticide amount used. Another aspect of this test was to familiarise ourselves with techniques, time consumption and routines for the coming trials.

Design

A straight baseline of 500 m, 90° to the wind direction, was marked by cars at each end. At 200, 250 and 300 m a line of 500 was drawn downwind and glass slides for droplet analysis set up at 10, 20, 40, 70, 100, 150, 200, 250, 300, 400 and 500 m.

Results

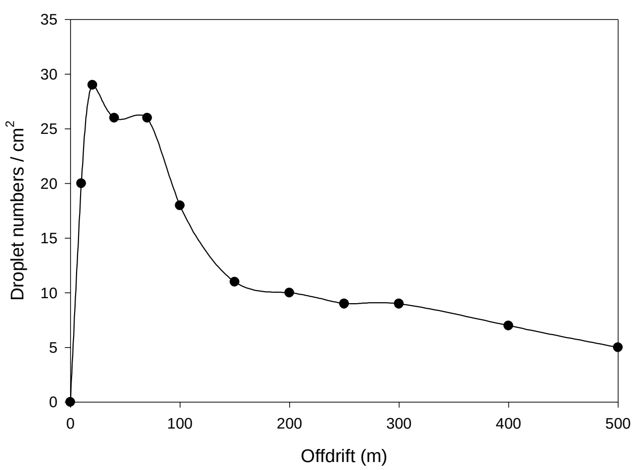


Figure 3. *Swath width at wind speeds of 1 - 1.5 m/s and flight altitude of 5 m.*

By watching the flight screen while having the cars marking the baseline, the pilot was able to make a first test of the system. The wind was weak, 1 - 1,5 m/s, and the maximum in droplet deposits occurred at 20 m (Fig. 3). The result is close to the theoretical expectations, where an off-drift of 14.1 to 42.9 m is expected with droplet sizes of 80 - 120 µm, wind speed 1.0 - 1.5 m, flight altitude of 5 m and no turbulence or other disturbing factors (calculations based on a computer spreadsheet program written by P. Ottesen, which can be supplied on request). Likewise, an application rate of 1 l/ha and droplet sizes of 70 - 120 µm would theoretically produce 56 - 11 droplets/cm^2, if droplets are treated as perfect spheres. Droplets of exactly 90 µm would give 26 droplets/cm^2. The results indicate that most likely the majority of the droplets were in the range 80-90 µm. This was confirmed by measuring the droplets on the slides under a binocular microscope in Norway.

Off-drift according to flight altitude

Purpose

To evaluate the possible benefit of the GPS navigation and spray monitoring systems in relation to factors like wind speed and flight altitude.

Design

A straight baseline of 3.4 km perpendicular to the wind direction was driven with the car. A red empty fuel barrel was placed at 1 km to indicate the end of 5 m altitude spraying. Barrels at 1.2 and 2.2 km indicated the start and end of 10 m altitude spraying, and barrels at 2.2 km and 3.4 km the start and end of 15 m altitude spraying. In the middle of each 1 km spraying section, three rows, 50 m apart, were driven downwind 90° to the baseline. Glass slides for droplet counting were set at 0, 10, 20, 40, 70, 100, 150, 200, 300 and 500 m.

Results

The wind speed during the trial was 2.2 - 3.6 m/s, which is well within the recommended range for aerial control operations. At 5 m flight altitude most droplets were collected at 20 m, indicating that 5 m flight altitude is too low for delivering a homogenous sprayed area. 10 m was close to ideal, with a maximum droplet number at 150 m. The areas below these two curves (measured on graph paper), are approximately equal, showing that the total amount of droplets recorded are the same. However, at a flight altitude of 15 m, most droplets were lost, only a few of the largest ones reached the slides. The flight altitude is thus a critical factor that has to be controlled accurately. The result contradicts theoretical calculations on off-drift according to flight altitude, droplet size and wind speed (see results on previous page). This emphasises the need for field recording of swath widths.

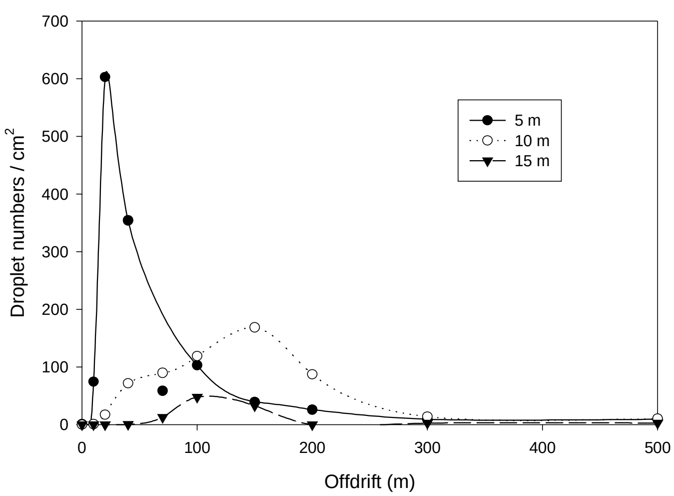


Figure 4. *Swath width assessment at wind speeds of 2.2 - 3.6 m/s and flight altitudes of 5, 10 and 15 m. The isolated filled circle at 70 m is omitted, since it was hidden behind a bush in a wadi.*

As mentioned earlier, an application rate of 1 l/ha with droplet sizes of 70 - 120 µm is expected to produce 56 - 11 droplets/cm^2. Fig. 4, 5 and 6 shows that the slides typically had more than 100 droplets in the indicated droplet size range. How can this be explained? By placing some slide horizontally on the ground, we saw that they collected very few droplets, i.e. 1 - 6 / cm^2. The results thus indicate that spraying at high wind speed, i.e. at 3 m/s and above, may be more effective in locust environments with little vegetation than spraying at low wind speeds, since the droplets will fly along the ground until they reach a target, which might be a locust, a tree, bush or some grass. These objects will receive far more droplets than expected from a homogenous distribution.

Comparison of spraying a 2 x 1 km rectangular area with and without GPS navigation

Purpose

To compare the possible benefit of DGPS navigation with conventional compass navigation by recording track spacing deviation and droplet distribution. Is the droplet distribution the critical factor, in the sense that the inherent variations in droplet distribution mask the improvements caused by DGPS navigation?

Design

A straight baseline of 2 km, 90° to the wind direction, was marked by cars at each end. At each 400 m, starting at 200 m, lines 500 m in length were drawn downwind (perpendicular to the baseline). Glass slides for droplet analysis were set up at 0, 100, 200, 300, 400 and 500 m, giving a total of 30 slides for each plot. The plot was first sprayed by the pilot by visual and compass orientation. Only the first sprayed line was marked with a car at each end. This is a very common situation during Desert Locust control operations, if flag men are not available. The pilot, who had extensive experience in aerial spraying operations, did his best to treat the area uniformly. The second spraying, using the same plot, was done using DGPS navigation. The trial was repeated three times in three different areas (i.e. three replicates of spraying an area with and without GPS). However, in the last GPS flight we purposely put in two "errors". These were double spraying of two tracks and no spraying of two other tracks (see Fig. 6).

Results

It turn out to be difficult to quantify the improvements in pesticide coverage when using DGPS navigation, compared to the coverage obtained by conventional navigation. Even with DGPS navigation, there was large variation in droplet numbers from place to place (Fig. 5). However, we clearly saw that miss-navigation had measurable implications on the ground (Fig. 6). In addition, the flight printout showed great improvements in flight track spacing through DGPS use. We obtained six such printouts, three with DGPS navigation and three without. Fig. 7 shows a typical result for non-GPS flight, i.e. that the GPS system was not visible for the pilot, although the computer recorded the flight tracks. An example of spraying with DGPS navigation is shown in Fig. 8. The very precise track spacing and pesticide application is obvious. The thin lines show the tracks of the aircraft, the shaded tracks show sprayed areas. During the trial without GPS (Fig.7), the baseline (the lower line on the printout) that was marked by cars was perfectly flown, the three next ones were also quite accurate. Later, when the pilot lost sight of the cars, there was both under-spraying and double spraying. Finally, there was a displacement of the starting and ending points..

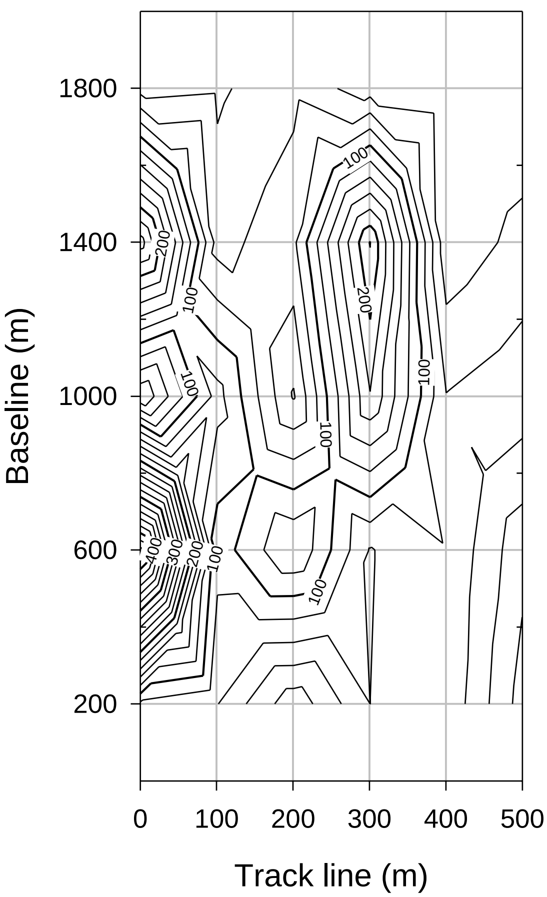


Figure 5. *A contour plot of the droplet number / cm^2. The track line scale is 2 x the Baseline scale. Even with DGPS, there is large variation in droplet distribution, presumably caused by unstable wind, variation in flight altitude, ground vegetation etc. Spraying details: Date: 28. March 1998, 9.45hr, Wind speed: 4 - 6 m/h, Temp.: 33°C, RH: 55%.*

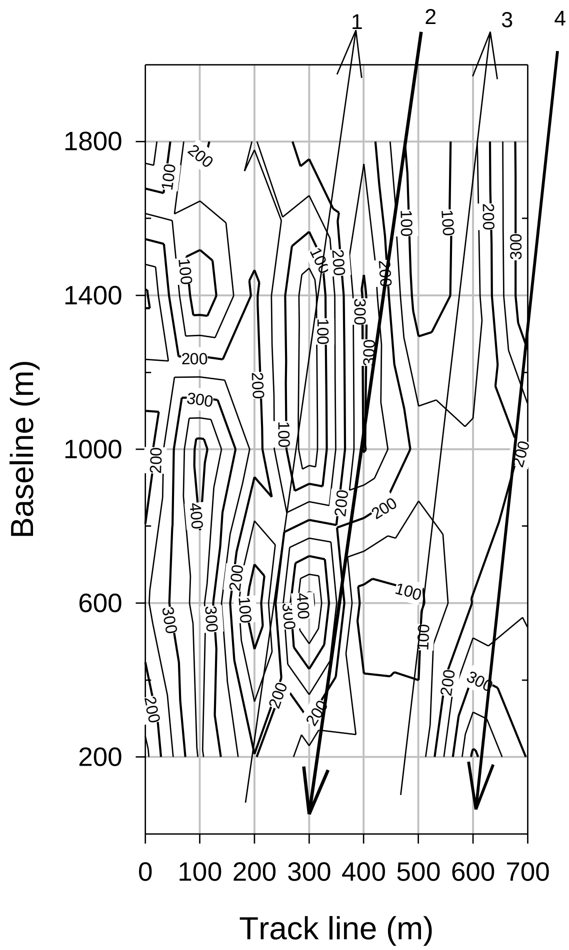


Figure 6. *A contour plot (droplet number/cm^2) of a DGPS flight where the thin arrows 1 and 3 indicate tracks that were NOT flown or sprayed due to miss-navigation. Instead, the neighbouring tracks were double sprayed (the bold arrows 2 and 4). The baseline is in downwind direction The droplet analysis clearly show the over- and under-application on the ground. Spraying details: Date: 2. April 1998, 9.00hr, Wind speed : 7 – 10 m/h, Temp.: 30°C, RH 35%.*

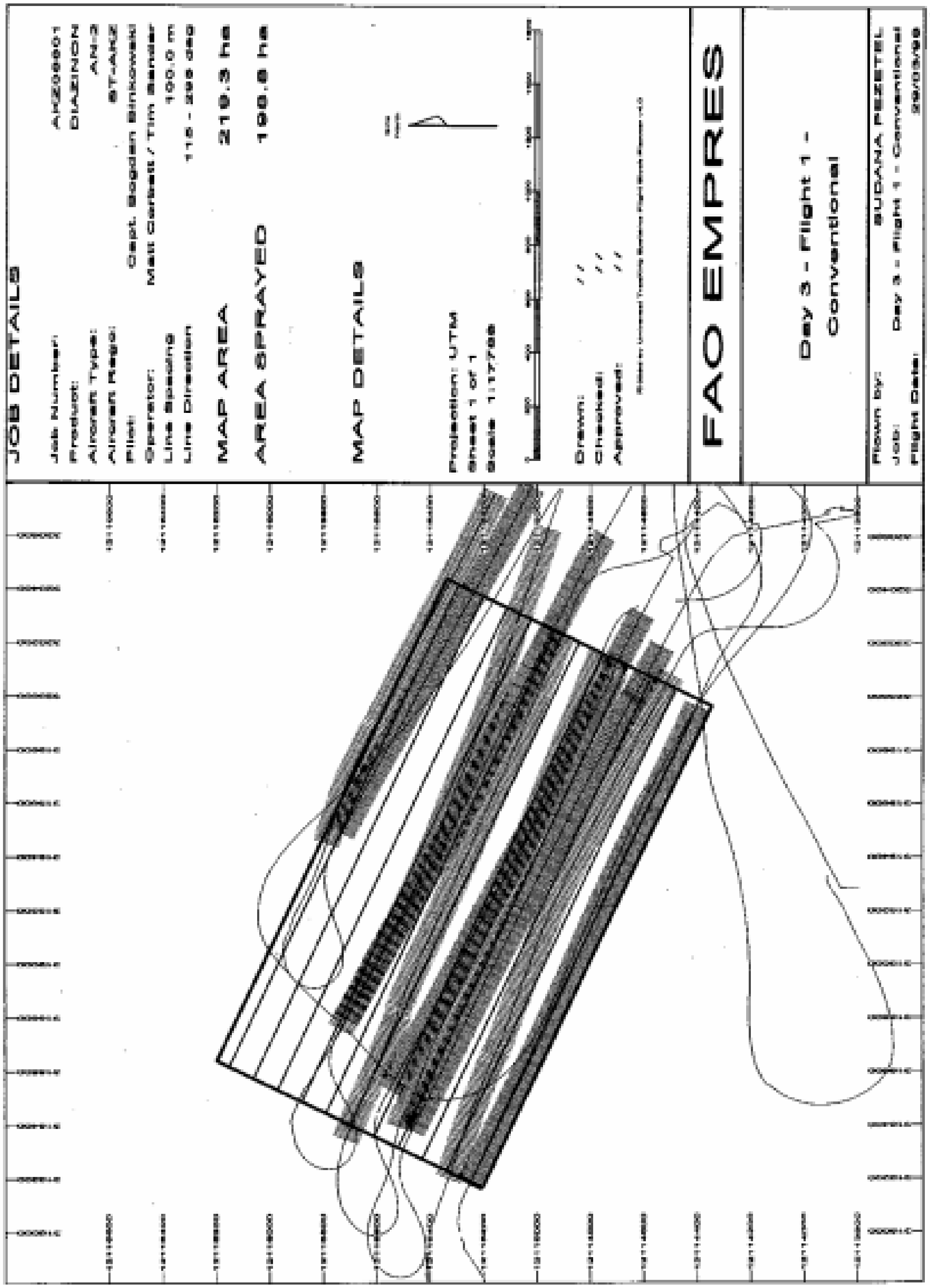


Figure 7. *Printout of a flight record where the pilot did not use the DGPS navigation system, although the flight track was recorded by the computer. The thin lines show the tracks of the aircraft, the shaded tracks show sprayed areas. The baseline is the lower line on the printout.*

Polygonal area with exclusions

Purpose

To test the ability of the DGPS to assist in treating irregular areas of swarms and to avoid areas that are vulnerable to pesticides, like villages, pastures, lakes, rivers or marshes.

Design

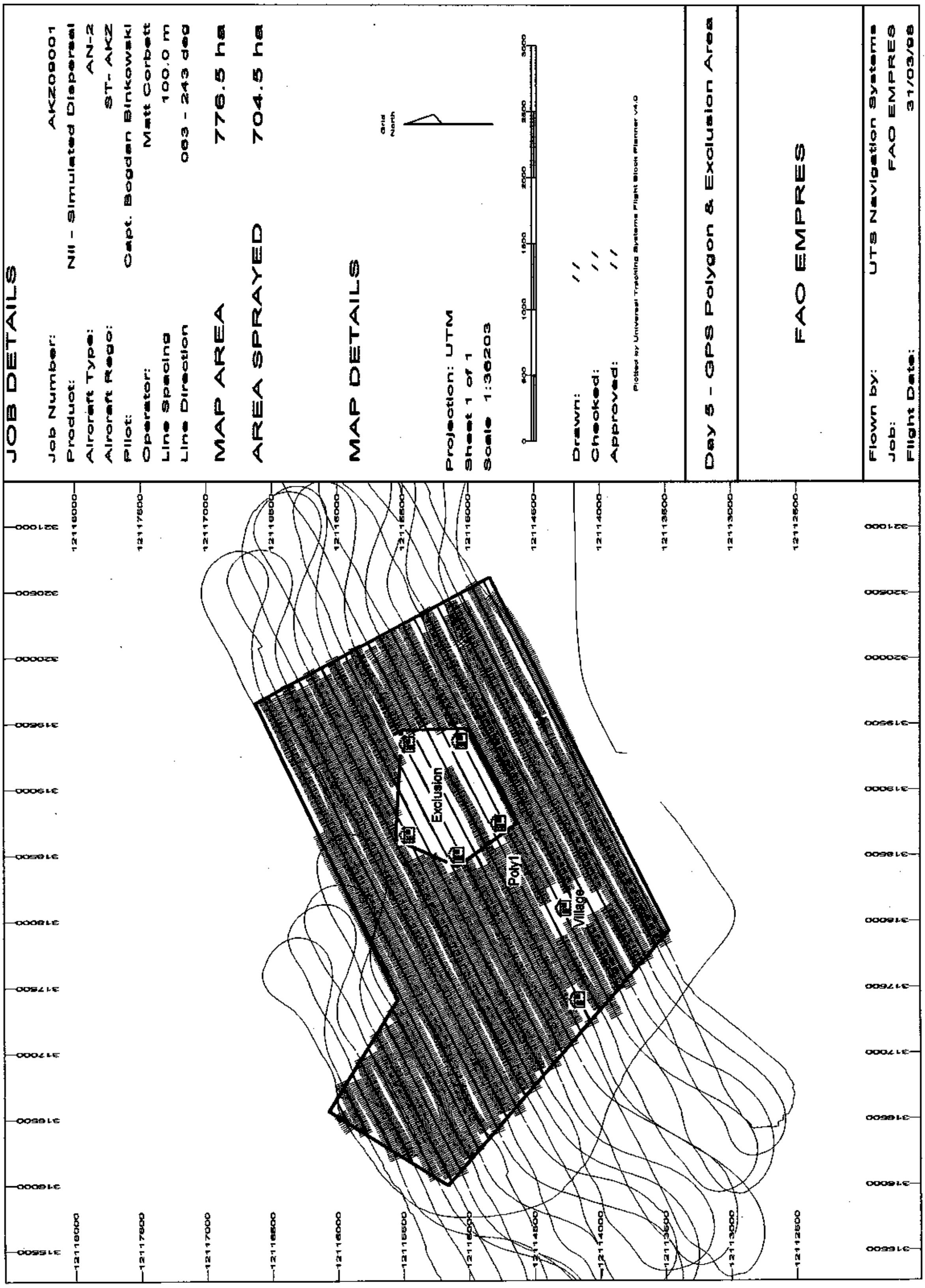
This trial was a navigation test where pesticide application was simulated during flight by pressing the "spray on" button, but no pesticides were used. An area meant to simulate a swarm of medium size was designed as an irregular hexagon of 776.5 ha, with a 3 km long side to be sprayed first. Inside this area, an irregular smaller pentagonal exclusion area was placed simulating a village to be protected. In addition, the pilot was instructed to stop spraying if he saw grazing animals, houses, people or other objects to be protected.

The designed area was driven in the field using a compass and the speedometer of the car. The corners in the two polygonal areas were recorded with a handhold GPS device. These co-ordinates were given to the pilot who plotted them into his system.

Results

Fig. 8 gives the flight record for spraying. The area was sprayed with a high degree of precision. The excluded area (village) was on one occasion sprayed, because it was forgotten to turn off the "Spray ON/OFF" button. This emphasises the need for an automatic connection between the plotted coordinates and this button. Such a connection would enable the pilot to concentrate on flying, or on looking out for objects, not plotted into the system, that should be avoided during spraying. In our trial, there were two such areas, a 2nd small village, and a single house.

Next page: Figure 8. *Printout of a flight simulating spraying in a polygonal area, where three objects, plotted in before flying, were not to be sprayed. One of the tracks was still sprayed into the largest exclusion area. This was due to a manual error by the pilot, emphasising the need for developing an automatic ON/OFF spraying button.*


JOB DETAILS
Job Number: AKZ09001
Product: Nil - Simulated Dispersal
Aircraft Type: AN-2
Aircraft Rego: ST-AKZ
Pilot: Capt. Bogdan Binkowski
Operator: Matt Corbett
Line Spacing 100.0 m
Line Direction 063 - 243 deg
MAP AREA 776.5 ha
AREA SPRAYED 704.5 ha
MAP DETAILS
Projection: UTM
Sheet 1 of 1
Scale 1:36203
Drawn: / /
Checked: / /
Approved: / /
Day 5 - GPS Polygon & Exclusion Area
FAO EMPRES
Flown by: UTS Navigation Systems
Job: FAO EMPRES
Flight Date: 31/03/98
Exclusion
Poly1
Village

Barrier spraying

Purpose

To demonstrate the use of DGPS navigation in barrier spraying, i.e. to fly a large area with a track spacing of 1 km.

Design

Four tracks of 3.4 km were flown (the first one combined with the experiment "off-drift according to flight altitude”). Pesticides were only used on the first track, not on the next three ones.

Results

The area was over-flown very precisely, with hardly any deviations from the theoretical best way, i.e. straight lines 1 km apart (Fig. 9). Within seconds, the pilot could have defined another side of the quadrate as his baseline, and then done spraying in a cross pattern.

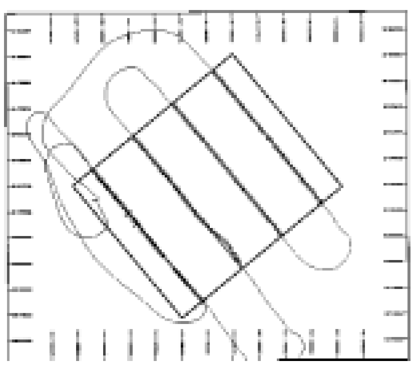


Figure 9. *A barrier sprayed area of 4 x 4 km, with 1 km track spacing.*

Marking an area by over-flying

Purpose

To test the use of the Arc II for cases where GPS coordinates are not available from ground personnel. This might be the case when an area has not been logged, no GPS equipment is available on the ground or radio communication is broken. To test the accuracy of aerial positioning logging.

Design

A regular pentagonal area with 1 km sides was marked in the field by a car given pre-defined driving directions. Empty red fuel barrels were set up at each corner and the UTM coordinates registered with a handhold GPS device. These coordinates, however, were not given to the pilot, who registered the points by pressing the "next line" button when over-flying one of the corners (see AGS III Operator's manual).

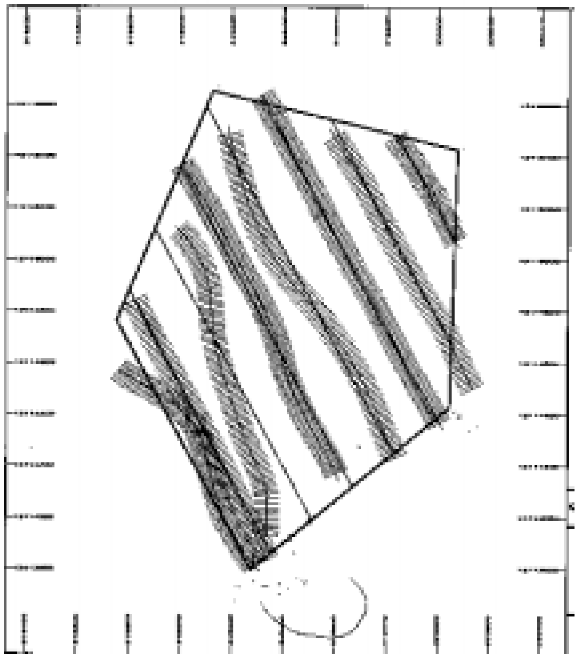


Figure 10. *An area located by the pilots by over-flying the various corners of the pentagon. Deviations from a regular pentagon was probably due to the ±100 m inaccuracy of the hand held GPS. Shaded bars are area sprayed, with 200 m track spacing.*

Results

The area was over-flown and the co-ordinates plotted when flying above the barrels. A few points had to be registered twice. We did not quite obtain a regular pentagon, although the corners were accurately registered by the speedometer of the car, compass and hand held GPS. However, none of the co-ordinates registered from the air deviated more than 100 m from the intended points. This, in effect, matches the low precision of the hand held GPS (± 100 m), which appeared to be the source of the deviation. Such possible deviations should be kept in mind when marking small areas, for instance villages or ponds for chemical exclusions.

Additional analyses and evaluations

Simulations of several polygons

Instead of marking an area for spraying, which contains several exclusion areas, the DGPS can also be used for marking an area, within which only some smaller areas should be sprayed. This may be required when large swarms break up in smaller units, or when hopper bands are broken up in submits. In the example shown in Fig. 11 an infested area contains of four sub-plots to be sprayed. During an aerial operation, most likely the whole area would have been sprayed. However, by following the track lines, only 36% of the lines cross the infested areas. Mapping the infested areas before spraying will thus significantly reduce the amount of chemical applied, with the corresponding economical and environmental benefits. Due to time constraints the area shown in Fig. 11 was not flown, but would not have presented any particular problem.

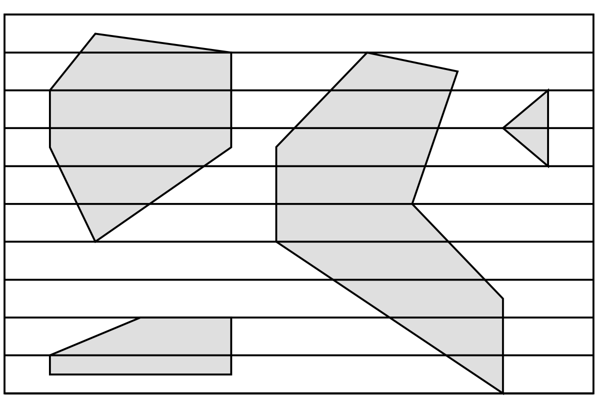


Figure 11. *A swarm has broken up in four sub-swarms. Instead of treating the whole area as one block, 64% of the pesticides can be saved by treating only the infested areas***.**

Cost/benefit aspects of the DGPS navigation in combination with spray recording

The 1986-89 control campaigns involved substantial efforts by the national governments of the locust-affected countries as well as by the international donor community. It was estimated that the plague involved the application of approximately 13 million litres of pesticides and was supported, in Africa alone, by more than US $ 200 million in international assistance. In West Africa and North Africa, almost 4 million litres of pesticides were used during the 1992 to 1995 campaigns and US $ 50 million in international assistance was provided.

During such large campaigns, investments in the DGPS navigation system and spray recording system are clearly justified. The cost of the system we used was US$ 25,000 for the AGS III navigation system, and US$ 30,000 for the spray monitoring system. The following summarizes the main economical and environmental benefits of the system.

- Pesticide reduction:
  - Precise track spacing and accurate control of flow rates of the individual spinners eliminates the need for the current overdosing used to compensate for inaccurate application and calibration. Given that the calibration of the equipment and the application of pesticides is correct, previous trials by the Norwegian team members have shown that the pesticide dosages, compared to those currently used, can be reduced by 50 to 90%. The limit for possible reductions depends on the type of pesticide and the species treated. The pesticides so far tested are fenitrothion, lambdacyhalothrin, deltamethrin and an the insect growth regulator (IGR) teflubenzuron.
  - A large swarm consisting of several sub-swarms can be treated as several units, eliminating the need for blanket spraying of the areas in between these sub-swarms that do not have locusts.
- Environmental savings:
  Vulnerable areas can be excluded from treatment.
- Operational efficiency:
  - More areas can be treated, since locust ground personnel can concentrate on prospecting and coordinate the mapping of areas infested by swarms or hoppers.
  - Flag-men and cars do no longer have to wait for the pilot to arrive.
  - More precise flying will reduce flight hours.

Pilots evaluation

The pilot from Sudana Pezetel, B. Bogdan, was using the DGPS navigation system for the first time, and we asked him on his opinion on the system. His comments were:

- DGPS will undoubtedly become very important and a standard for all types of aerial spraying.
- Its ability to give good track spacing is beyond doubt. There is not any longer a need for looking for obscure landmarks.
- Most important is that all disputes on area treated would come to an end. The employer will have a clear document and map giving all necessary details on areas treated, application rate and volume of pesticide used etc. (cf. appendix).
- The manual for installing the system (i.e. the AGS III) was clear, a pilot mechanic can do the installation himself. Experts are not necessary.
- Pilot training is necessary, but most of it can be done on the ground using a PC which simulates the system.
- Given good ground training, one can use the system in the air almost immediately.

Discussion

DGPS Marking Systems

The use of a DGPS marking system during aerial locust control operations gives significant advantages in terms of reduced pesticide use as well as improved protection of humans (locust control staff and people living in or near the areas treated), livestock and non-target organisms, e.g. those found in environmentally vulnerable areas. In addition, aerial locust control operations become more efficient through savings in man power and reduction of flying hours for a given area to be treated. Further, accurate and consistent recording of aerial control operations, often neglected during locust plagues, is automatically done by the system. Direct entry of the spraying records into the FAO SWARMS database (or similar databases) would be possible, but would require the establishing of a system for automatically converting UTM into normal coordinates. Computer sub-routines doing such conversions already exists.

While it would be difficult to compare in detail the costs of the system tested with the above advantages, the trials indicated that an investment in such a system would already be justified for a relative small aerial control operation. Considering savings in pesticides alone and using a conservative estimate of a reduction in pesticide use by one half, the investment in the system would be already returned after treating approximately 12,000 hectares.

The system tested would not require any more improvements in terms of accuracy of navigation. In fact the accuracy of spraying a given area is no longer limited by navigation, but by other factors like changing wind directions or the time lag between switching the atomizers on and actual ejection of the pesticide. Further improvements and refinements are desirable along such lines and are described below. A major still unresolved problem is the uneven distribution of pesticide droplets on the ground and the vegetation. This is connected to poorly understood interactions of temperature, humidity and vertical air movements under typical locust control conditions. The trial results showed that flight altitude is very critical in terms of droplet distribution and a better understanding of these interactions could enable the improvement of theoretical models which predict droplet distribution in relation to flight altitude.

Spraying equipment

The magnetic tachometer was found to be a major improvement in recording the rotation speed of the atomisers, and therefore a tool for more precise calibration and quality control. Previously the speed had to be read from a table on the basis of flight speed and propeller blade angle, since contact tachometers (steel wire that vibrate in harmonic amplitudes with the rotating device) cannot be used during flight. The system used had only one magnetic tachometer, but the software enables the use of one on each atomiser, and gives the speed of the individual atomisers as a histogram on the flight screen.

Another important tool is a flow-meter that can record the amount of pesticides sprayed. Unfortunately the system tested did not include one and expensive flying time was used for measuring the amount of pesticide used according to flying time, since the pumps only operated during flight. An electrical pump should also be used, so that pesticides can be pumped out while the aircraft is on the ground. By placing buckets below each atomiser, their individual performance can then be tested.

A factory-calibrated flow-meter attached to each atomiser will give the desired accuracy and prevent time-consuming calibrations prior to flights. The flow-meters can then be connected to the onboard computer and give exact information on performance and total flow. Total flow can then be adjusted on board during flight if the viscosity of the chemical is changed due to temperature or other factors.

A major factor of variability is the droplet size spectrum. Micronair supplies a graph giving the range of droplet sizes according to atomiser rotation speed, but it is based on water. Pesticides have a higher viscosity and droplets will most likely be larger than indicated. Also, viscosity will change with temperature. It is recommended that a range of the most common pesticides are tested for droplet size spectra in laser chambers, where temperature, pesticide type, viscosity, flow rates and rotation speeds can be recorded. This would result in an improved graph (or several graphs) for field use.

Recommendations

Necessary components for a system to be selected

On the basis ofthe trial results we recommend that all aircraft for Desert Locust control are equipped with an integrated DGPS navigation system combined with a spray monitoring systems. In addition to standard components, this system should at least have:

- A light indicating that spraying should start, but preferably full integration of the spray ON/OFF switch triggered by the co-ordinates for spraying ON/OFF as logged into the system.
- A print out facility giving the areas sprayed and the actual flight paths.
- An export facility of the co-ordinates to a GIS program, preferably Arc Info which is used for storing information on Desert Locust control campaign etc.
- A spray monitoring system that record on each individual atomiser
    - flow rates,
    - rotations per minute (tachometers).
- An altimeter, since DGPS do not record flight altitudes precisely enough. Although expensive, an altimeter is a most important tool for controlling swath widths, which are extremely variable according to small changes in flight altitude. Laser-altimeters are available in the market and can easily coupled to the flight-guiding system. Desired flight altitude can be set prior to flight and according to wind velocity (to minimize offdrift).
- A possibility for switching to the Russian GLONASS navigation system in case a control operation was to take place in an area without GPS coverage. Unfortunately, the Sahara is one of the least covered areas by the GPS satellites.

Future development

Further improvements of the system, especially for Desert Locust control operations, could involve deveopment in the following areas:

- A time lag facility compensating for the time lag between pressing the spray on/off button and the time when the atomisers actually starts or stops ejecting the pesticide. Even if this time lag is only 1 second it can have significant consequences for the protection of small vulnerable areas, like Sahelian ponds, because the aircraft will fly more than 100m during that time.
- A possibility to move marked areas on the flight screen by dragging the mouse. In order to compensate for off-drift according to wind speed, wind direction and flight speed, it would be desirable to move small areas to be protected in a fan-like manner some 100 m.
- Installation of a button, dedicated to changing the direction of the track spacing, in order to allow for quick changes in case the the wind direction should suddenly change.
- Development of equipment with DGPS navigation for ground vehicles. An important aspect would be to integrate the flow rate of the chemical with the vehicle speed and

driving direction, with low speed and off track conditions giving low flow-rate, and high speed and smooth terrain giving high flow rate.

Appendix: Output from the spray monitoring system corresponding to the flight shown in fig. 5.

GENERAL FLIGHT REPORT

Day 3 - Flight 2 - GPS Operational
28/03/98

Job Number	AKZ08802
Chemical	DIAZINON
Aircraft Type	AN-2
Aircraft Rego	ST- AKZ
Dispersal Equipment	Micronair AU5000
Pilot Name	Capt. Bogdan Binkowski
Operator Name	Matt Corbett / Tim Sander
Flow Rate	26.0 Kg/min
Application Rate	1.0 Kg/Ha
Bucket Capacity	300.0 Kg
Swath Size	100.0 m
Line Spacing	100.0 m
Flight Direction	296 - 116
Total Map Area	199.4 Ha
Total Exclusion Area	0.0 Ha
No of Flight Lines	10
Total Flight kilometres	19.9 Km
Total Product kilometres	19.9 Km
Total hectares sprayed	211 .1 Ha
Total kilometres sprayed	21.1 Km
Total time flown	0h24m46s
Total time sprayed	0h07m55s