(54) Title: DIFFERENTIAL GLOBAL POSITIONING SWATH GUIDANCE SYSTEM WITH DUAL ROW LIGHTBAR AND FLOW CONTROLLER APPARATUS AND METHOD

(57) Abstract

A base station (9) and a ground or airborne rover (13, 16) receive satellite (1, 2, 3, 4) DGPS signals (5) which base (9) corrects and sends (6) to rover to accurately position rover to dispense agricultural products in a predefined field (20) using selectable swathing patterns (Figs. 3-6). Rover's computer controlled DGPS receivers (41, 42), convert rover's present position relative to the swath to a lateral displacement and an intercept angle. Lateral displacement/intercept angle are displayed by lighting an equivalent number of lights (151, 153)/(152, 154) on the proper half of an upper/lower row of LEDs in a lightbar (46) and by a number in a left/right digital display (157/156) of the lightbar. A flow controller monitors DGPS provided ground speed and actual position to meter the flow rate of product dispensed. The lightbar window is angled and nonreflective.
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DIFFERENTIAL GLOBAL POSITIONING SWATH GUIDANCE SYSTEM
WITH DUAL ROW LIGHTBAR AND FLOW CONTROLLER
APPARATUS AND METHOD

Fields Of The Invention

The present invention relates generally to apparatus and methods of use of
satellite-generated signals for locating, positioning, guiding and tracking ground and
airborne vehicles, and, more particularly, to an improved global positioning system with
differential correction for providing highly accurate swath-to-swath guidance for
agricultural equipment and devices, including a light bar to provide even more precise
guidance for the operator to position himself on the next swath in the pattern and a
controller to automatically continuously monitor vehicle ground speed and position and
to adjust and maintain the flow of agricultural products over a specific land area at the
desired rate.

BACKGROUND OF THE INVENTION

A. Prior Effective Soil Management Techniques

One of the truly pivotal inventions of mankind is the plow. Even in its earliest
embodiment as a simple sharpened stick drawn by a human being, this leap in
agricultural technology brought about a massive revolution in productivity. The increase
in productivity resulted from the reduced workload associated with planting. Whereas in
the past each seed had required its own separately dug hole or plot in the soil, even the
most primitive plow vastly simplified the digging and planting task by leaving behind it
something like an open furrow.

Furrows tend to take the general form of lines, hopefully more or less evenly
spaced, across the area to be planted. The objective is simply to maximize the use of the
available planting surface and optimize yields. The more accurate and evenly spaced the
furrows, the better the yield per acre, provided that seed spacing and other soil
management elements are optimized as well. However, even spacing of furrows is at least
half of the challenge to the farmer in maximizing his yield.

Even spacing of furrows, both straight and contoured, as well as even spacing of
seeds, soil nutrients, fertilizers, pest control agents and other elements required for
successful agricultural operations are the fundamental objectives of the present invention.
1. **Visual Reference Systems**

Historically, furrows and rows have been laid out and executed using visual references almost exclusively.

a. **Paper Flaggers**

For years aerial applicators have used a system known as paper flaggers. Paper flaggers are tightly folded packets of cardboard and tissue paper which, when released from an ejector mechanism on the aircraft, unfold in the airstream and flutter down to earth in a long, white streamer leaving a visible marker for the pilot to use in locating his last flight path over the ground. This becomes his reference in estimating a proper displacement to his next desired swath.

The problem pilots experience with paper flaggers are those to be expected. Windy conditions carry the markers far from their intended landing point. In trees, shrub cover, or rough terrain, the flags tend to become lost or difficult to spot in time to make the next swath entry. Where paper flags have been used more than once during a season, confusion often arises as to which of the several flags in view is the latest one dropped. Of course, flaggers are useless for night operations.

b. **Foam Dispensing Devices**

Another visual technique for establishing spacing and guidance is the so-called foam dispensing system. Utilized primarily in ground spray applicators, this technique relies upon a pair of flexible hoses dangling from the far ends of the spray boom. As the spray rig moves through the field, the operator presses a button in his control cab to activate a valve which releases a small volume of foam, very similar to shaving cream. These foam discharges are spaced at intervals several seconds apart and are used by the operator on his next swath to determine his proper position with respect to the last swath.

Again, several key problems have plagued this guidance system. With spray booms 80 to 100 feet in width the operator can, at best, only estimate the true position of the end of his spray boom with respect to the blob of foam left behind on his last pass. Winds tend to blow the light foam balls across the fields like tumbleweeds. In hot weather the foam quickly melts and disappears. The foam settles and hides in field stubble, leaving the operators to guess at their position. Because of the difficulty of
estimating distance to the end of the boom, foam equipped spray rigs rarely operate at night.

2. **Electronic**

More recently, attempts have been made to put electronics to work for the farmer.

a. **Video Cameras**

One attempt to harness electronic technology was an obvious extension of the visual concepts. In a system to Pryor (U.S. Patent No. 4,482,960) video cameras and microprocessors were installed around a given field and on the tractor which was to operate there. The system allowed for optical cues to guide the tractor either in a completely automatic (robot) mode or through remote control provided over a video and data link to some control facility. This system was, thus, visually limited.

b. **Field Wire Grid**

A different and non-visual approach involved the use of a grid of wires buried just below the surface of a field. The wires provided automatic guidance to a tractor or other vehicle as it passed along the length of the wire. This concept failed to gain acceptance in the agricultural community for several reasons. Laying out the wire grid represented a substantial investment. The wire was subject to frequent accidental severing, rendering the system useless. A significant percentage of the soil was lost to hosting the wire and, thus, could not be put into production.

c. **Laser/Reflector**

Even more advanced applications of electronic technology in both airborne and ground applications were attempted in systems to Tsumura (U.S. Patent No. 4,488,233), Davidson (U.S. Patent No. 4,225,226) and Dyke (U.S. Patent No. 4,700,301). Despite its remarkable capabilities, the laser technology used in these systems is limited to clear air and line-of-sight conditions which are often difficult or impossible to achieve in the agricultural operating environment. Spray and dust, inherent in agricultural ground and aerial applications, by its nature works to the detriment of any laser-based guidance and tracking system because the laser beam, diffused by dust or spray, can no longer yield
precise positioning data and may be disabled altogether.

A further major disadvantage of such laser-based systems is that they are geographically limited. Any vehicle carrying laser-emitting guidance equipment must operate within the geographic bounds of a finite number of reflectors which enable the on-board equipment to carry out the necessary positional calculations. The same limitations apply when the reflector is the on-board equipment and the laser emitting sources are on the ground. In effect, the mobile unit is captive to an area described by a line-of-sight beam linking the laser emitter with at least two dedicated and carefully installed reflectors.

d. Radar/Transponder

Similarly limited in terms of its operating area is the radar/transponder technology which has been developed and marketed by several vendors. In a system to Dano (U.S. Patent 4,398,195) the vehicle (aircraft) is equipped with a radar transmitter and a receiver which receives signals from multiple stationary transponders located so as to provide a triangulation fix to the vehicle's on-board computer. As the range of the vehicle changes relative to the transponders, the on-board computer calculates a reasonably accurate ground track and speed.

As was the case with the laser systems, the radar systems are absolutely limited in range to an area covered by the line-of-sight to at least three, and preferably four, system transponders. Also, the cost of installing and maintaining such a system is often prohibitive, and the prospect of multiple operators sharing the same tri-sponder system is impractical due to system degradation from concurrent use by multiple vehicles. A further major problem is lack of reliability. If one transponder fails, one battery dies, one lightning strike takes its toll, then the entire system is disabled. Thus, in actual experience, these so-called tri-sponder systems have been widely tried throughout the agricultural industry, but have failed to gain acceptance.

e. Loran-C And Turn Indicators

A further electronic system used to assist a pilot in swathing operations to find his next swath is a LORAN-C navigation system for macro-positioning assisted by a needle gauge or light bar for micro-positioning. The Loran-C system was well known for
maritime and airborne general navigation. The light bar typically was an instrument placed in an aircraft and had a single row of three multi-color lights. See, for example, the Davidson '226 patent, supra. The center green light indicated on desired track, the left red right indicated steer left to intercept desired track and the right orange light indicated steer right to intercept desired track. Such prior light bars are in effect the same as a needle type turn indicator or audible tone series well known to aviators.

The major problems with these rudimentary systems were obvious. They lacked universal applicability and sufficient accuracy. Loran was fine for shipboard navigation systems but is not available over many land areas, and its accuracy is measured in miles, not meters. Not only is the turn needle and light bar no more accurate than the system that drives it, but also, these early instruments gave the pilots little more guidance than which direction to steer, being unable, for example, to indicate lateral displacement from desired track in feet or intercept angle to desired track in degrees. Moreover, these instruments were not well adapted or placed to be visible to the pilot for use with just his peripheral vision, such as is mandatory when flying close to the ground.

Thus, there has been a long felt need for a cost effective, non-geographically limited, high speed, computer implemented, positioning system which could universally, accurately and reliably position and guide an operator or a pilot flying close to the ground to within centimeters of his initial and each subsequent swath and keep him on track as he drove or flew the swath at any time 24 hours a day.

B. Prior GPS And DGPS Non-Agricultural Uses

The technological advantages inherent in a satellite system known as the Global Positioning System ("GPS"), addresses virtually every disadvantage or problem cited in the prior art. Technology combining satellite positioning with high-speed computer processing makes possible a level of guidance and positioning accuracy vastly exceeding the best optical algorithms in their best operating environment. The satellite signals are impervious to dust or spray and are of equal utility night or day. GPS provides a 24-hour coverage enabling precise (25 cm.) positioning and tracking world-wide, eliminating the need for range limiting tri-sponders.

Supported by U.S. taxpayers and managed by the U.S. Department of Defense, the satellite signals are available to all users free of charge. GPS receivers and related
equipment have undergone a rapid price reduction as utility and popularity of the technology has mushroomed. Current pricing for highly accurate, differentially corrected GPS equipment is well within the bounds of sound economic return. Base reference stations for providing differential corrections to enhance the accuracy of basic GPS, and even the broadcast differential correction messages themselves are also now priced to be within the economic reach of a large segment of the agricultural community.

Most significantly, using differentially corrected GPS ("DGPS"), it is now possible and cost-effective to create highly accurate and detailed logging records which can include such elements as time, position, including altitude, track over the ground, true ground speed, as well as a virtually unlimited number of system or functional parameters which the on-board computer may be programmed to calculate. Any or all of this data can be transmitted via data link to one or more remote monitors ("rovers") for real time following and evaluation.

Typical prior GPS and DGPS ground and airborne applications have included, for example, a system to Counselman (U.S. Patent 4,667,203) which determined position information between fixed points on the earth by measuring the phrases of the GPS satellite transmitted carrier signals without knowledge of the transmitted codes; a system to Chisholm (U.S. Patent 4,866,450) timing GPS signals transmitted by a fixed station to develop range information for receiving aircraft in an instrument landing system; a system to Joquet (U.S. Patent 4,894,655) which used DGPS signals transmitted by a fixed station to enable a rover to estimate its position corrected by the correction data in a microwave landing system; and a method to Allison (U.S. Patent 5,148,179) which used DGPS signals to position the rover relative to the fixed base by using dual frequency phase corrected carrier signals.

However, until the present invention, GPS or DGPS have not heretofore been used to accurately position agricultural ground or airborne vehicles or to monitor and control the amount and rate of agricultural products dispensed by such vehicles.

Thus, there is a long-felt need for a system which uses DGPS signals specifically in an agricultural environment.

C. Prior Non-Uniform Application Of Agricultural Products

As described above, numerous ground and airborne systems have achieved varying
degrees of effective soil management by guiding the vehicle or the pilot relative to the vehicle’s position over the earth. Once the agricultural vehicle is in its intended position, additional systems have attempted to physically regulate or control the amount of or rate at which specific agricultural products were dispensed from the vehicle. Such systems have included a multi-fertilizer spreader to Ortlip (U.S. Patent 4,630,773) which was a ground flow controller which metered different fertilizers at a desired volume per acre from different bins for different types of soil relative to the sensed speed of the truck and the truck’s position in a computerized digital soil map of the field determined by a low accuracy Loran type radio positioning system.

For airborne flow control of agricultural products dispensed in crop dusting operations, prior systems relied on the human interface, i.e., the pilot, to turn on the pump to prime the system near the field, to manually open the control valve to spray product, to monitor airspeed and flow rate, to manually adjust flow rate to desired rate for conditions and to manually close the control valve at the end of the first pass. On the next pass the pilot repeated the cycle.

Again, the problems with these systems were obvious. Ground and airborne flow controllers were initially no more accurate than their positioning system. Airborne flow controllers were highly inaccurate and could not realistically adjust for wind conditions or ground speed. Also they excessively burdened an already overburdened pilot flying within feet of the terrain below the level of surrounding obstacles, conditions not conducive to head-in-the-cockpit flying.

Thus, there has been a long felt need for an accurate, computer controlled flow controller for agricultural spraying operations that automatically, continuously monitored the vehicle’s ground speed and adjusted product flow to a predetermined rate leaving the pilot free to fly the aircraft and merely trigger the on/off system operation at the right moment.

**Summary of The Invention**

Set forth below is a brief summary of the invention in order to achieve the foregoing and other objectives, benefits and advantages in accordance with the purposes of the present invention as embodied and broadly described herein.

One aspect of the invention is in a rover guidance system for determining position
from satellite signals which includes a receiver for receiving signals from a plurality of satellites in a GPS constellation to determine a position of the rover over the earth, and for receiving data from a base radio to correct the position, and a computer to calculate a corrected position of the rover from the correction data wherein the improvement is means for using the corrected position to guide the rover in an agricultural swathing operation. The system continuously displays the corrected position enabling an operator to guide the rover.

Further features of this form of the invention include defining swath width and a right or left swath pattern layout, defining an A-B reference line for the swath pattern and computing a field layout in successive, parallel, equally spaced tracks in the direction preselected by the operator, defining a width of a field and computing field layout therefrom, using a keypad for inputting predetermined parameters, recording the positions traversed during the operation and reproducing the recorded data as a map of the field swathed.

A second aspect of the invention is a dual row lightbar for guiding a rover relative to a centerline which includes a display of rover lateral displacement from the centerline in one row, and a display of rover intercept angle with the centerline in the other row.

Further features of this aspect of the invention include displaying the lateral displacement by lighting an equivalent number of lights in the upper row and the intercept angle by lighting an equivalent one of the lights in the lower row, continuously indicating rover’s rate of closure with the centerline and the true course of the centerline by the rate at which the lit lights in the lightbar decrease toward the center of the lightbar, indicating the rates of closure relative to each other by the vertical alignment of the outboard lit light in each row as the lit lights decrease toward the center of the lightbar, and digitally displaying adjacent the lightbar rover lateral displacement from the centerline in direction and amount in the upper lightbar and left digital display and rover angle of intercept with the centerline in direction and amount in the lower lightbar and right digital display.

Another feature of this aspect of the invention is that the lights in the lightbar are preprogrammable so that when the lights are illuminated, rover deviations from the centerline are indicated in units equivalent to rover lateral displacement from the centerline in direction and amount and angle of intercept with the centerline in direction
and amount.

Still another feature of this aspect of the invention is the lightbar having a front transparent window covered by a circular polarized material affixed thereto supported in the housing at an upward angle relative to a horizontal plane substantially perpendicular to a front face of the lightbar such that the first reflection is of the dark inner roof of the lightbar whereby the readability of the lightbar is substantially enhanced even in direct sunlight.

A third aspect of the invention is a rover dispensing system which includes the DGPS receiver, and a flow controller for varying the amount of dispensed product as a function of rover ground speed and rover actual position over the earth determined by the DGPS to provide a predetermined amount of the product.

Further features of this aspect of the invention include computing means for automatically beginning and stopping flow upon receiving respective begin and stop signals from the operator, monitoring the ground speed, position over the ground and the flow rate of dispensing the product, automatically adjusting flow rate to dispense a predetermined amount of the product, prepositioning a flow control valve in the flow line to a best guess position while the flow in the line is off, controlling the flow control valve in an automatic flow adjusting mode in response to an operator’s signal when there is flow in the line, sensing pressure flow in the flow line to enhance response of the flow controller, and logging data describing the flight path traversed and the location and amount of product dispensed.
Brief Description Of The Drawings

Fig. 1 - Is a schematic view of an overall DGPS agricultural ground and aerial system of the present invention.

Fig. 2 - Is a plan view of a typical computer generated map of a farm field spray pattern resulting from using the present invention.

Fig. 3 - Is the computer generated field layout according to the algorithm used in the present invention.

Fig. 4 - Is a plan view of the right back-to-back flight pattern pre-selectable by the operator of the present invention.

Fig. 5 - Is a plan view of the right racetrack pattern pre-selectable by the operator of the present invention.

Fig. 6 - Is a plan view of the right squeeze pattern pre-selectable by the operator of the present invention.

Fig. 7 - Is a partial schematic block diagram of the DGPS and lightbar components of the system of the present invention.

Fig. 8 - Is a schematic view of the two types of antennas used in the present invention.

Fig. 9 - Is a side elevation view of the cpu/GPS unit of the present invention with PCMCIA card.

Fig. 10 - Is a front elevation view of the power supply/data receiver of the present invention.

Fig. 11 - Is a plan view of a PCMCIA Memory Card used to record the data describing the flight path traversed during a mission using the present invention.

Fig. 12 - Is a plan view of the keypad box of the present invention.

Fig. 13A- Is a plan view of the display box of the present invention.

Fig. 13B- Is a plan view of the swath screen of Fig. 13A.

Fig. 13C- Is a plan view of the navigation screen of Fig. 13A.

Fig. 13D- Is a plan view of the satellite screen of Fig. 13A.

Fig. 13E- Is a plan view of the program screen of Fig. 13A.

Fig. 13F- Is a plan view of the waypoint screen of Fig. 13A.
Fig. 14A - Is a plan view of the dual row lightbar of the present invention.

Fig. 14B - Is a schematic representation of simulated flight paths that can be digitally represented by the right digital readout of the light bar of Fig. 14A.

Fig. 14C - Is an enlarged view of the three center lights in the top row of Fig. 14A showing the color of three lights.

Fig. 14D - Is one example of a lightbar presentation for a hypothetical situation.

Fig. 14E - Is a second example of a lightbar presentation for a hypothetical situation.

Fig. 14F - Is a third example of a lightbar presentation for a hypothetical situation.

Fig. 14G - Is a right side elevation cross-sectional view of the lightbar of the present invention.

Fig. 15 - Is a table relating a suggested correlation between angle-of-intercept and off-track position for three types of sensitivity levels for preprogramming the upper and lower lightbar settings of the present invention.

Fig. 16 - Is a schematic block diagram of a prior art flow controller.

Fig. 17 - Is a partial schematic block diagram of the flow controller of the present invention.

Figs. 18A and 18B - Are operational flow charts of the process of the present invention.
Detailed Description Of The Preferred Embodiment

1. Overview
   a. The System

   The preferred embodiment and best mode of the present invention is the AirStar™ system with Spray Sentry, a product built and marketed by SATLOC, Inc. of Casa Grande, Arizona. The primary function of the AirStar with flow controller system is to provide airborne computerized DGPS agricultural product dispensing with real time parallel swath guidance and control of aerially sprayed products. The system also provides a wide assortment of related functions. Its sister product, Terrastar™, is for ground applications. The present detailed description is limited to the AirStar system.

   As seen in Fig. 1, the overall system 10 derives its navigation and guidance capability from a constellation of up to 24 NAVigation Satellite Timing And Ranging("NAVSTAR") satellites, 10,800 miles above the earth, which continually broadcast coded messages. Preferably, four to ten satellites 1,2,3,4 are at all times in view of base station GPS receiver 9 ("base") which receives the satellite signals 5 via antenna 11. The GPS receiver 9 when coupled with conventional special purpose computer software and hardware provides precise vehicle relative positioning and guidance with unparalleled accuracy.

   (1). GPS

   Each GPS satellite may be identified by its transmitted signal which also provides to users the positioning, timing, ranging data, satellite status and the corrected ephemerides (orbit parameters) of the satellite.

   Without differential corrections the GPS satellite positions received and computed by the Novatel GPS receiver used in the present invention are accurate to within about 100 meters. Factors which introduce errors into the GPS include ionospheric group delays, tropospheric refraction delays, ephemeris errors, and clock signals, for example. Importantly, for security purposes the Defense Department from time to time purposely randomly introduces errors, called "selective availability", into the data which the satellites broadcast. U.S. Department of Defense monitoring stations track and monitor the signals broadcast by the satellites, recompute the ephemerides and upload the resulting ephemerides corrections and timing corrections back to the satellites.
(2). **Differential Correction**

By operating in the differential mode with paired stations most of the above errors are eliminated and positioning solutions with accuracies of less than one meter error are consistently obtainable. Each pair consists of a fixed base and a rover which receive common satellite signals. Provided the two stations are in close proximity to each other, the bias errors are considered to be nearly the same and will be effectively cancelled by the differential corrections.

Because the fixed base's position is a known latitude and longitude, it can now compare its computed range measurements from the GPS signals to that of its actual known ranges. The difference between the calculated ranges and the known ranges is largely accounted for by the previously mentioned external bias errors. The fixed base now transmits computed range corrections over an established data link to the rover station. The rover, whose position is of unknown accuracy, will then correct its position solutions to reflect the fixed base differential corrections and its position solution accuracy will approach that of the fixed base because when the rover station receives the differential corrections, they are directly applied to its range measurements which cancels most of the bias errors as was the case at the fixed base.

More detailed information on the Global Positioning System used by the NovAtel GPS Receiver used in the present invention may be obtained by referencing the Novatel GPS Receiver User Manual dated October 28, 1992, Revision 1.0, pages 75-77, copyright 1992, NovAtel Communications Ltd., Lethbridge, Alberta, Canada. More detailed information on the differential correction process used by the Novatel GPS receiver used in the present invention may be obtained by referencing the Novatel GPS/CarD™ OEM Performance Series, 2100 Series User Manual dated April 27, 1993, Publication Number OM-20000003 Ver. 1.0, Software Release 2.01, pages 99-101, copyright 1993, Novatel Communications Ltd., Calgary, Alberta, Canada.

Thus, in the present invention, base 9 compares the received signals 5 representing its measured position on the earth with its stored known latitude and longitude and calculates an error signal 6 representing the difference ("differential correction") which it broadcasts via antenna 12 to airborne rover 13. Rover 13 also receives the GPS satellite signals 5 via round antenna 14 and the differential correction signals with Forward Error Correction ("FEC") via whip antenna 15. If rover 13 is within 200 kilometers of base 9.
the differential correction for both base 9 and rover 13 are the same, and rover 13 can accurately fix its position within centimeters of its actual position over the earth. Land rover 16 receives the same signals 5,6 as aforesaid via antennas 17, 18 respectively. The range of the base 9 transmitter may be extended by repeater 20 located on a nearby mountain which receives signals 6 and retransmits them as signals 7 which repeater 21 may receive and retransmit in the well known "digi-peater process". Rovers 13, 16 spray agricultural products via a swathing process the accuracy and efficiency of which is significantly enhanced by the present invention, as more fully described below.

As seen in Fig. 2, an area map 20 is shown in which field 21 was located and sprayed using a swathing pattern 33 developed by the present invention. Obstacles around the field include silo 23, house 24 and trailer park 25 to the north; pump 26 and garden 27 to the east; pump 28 and canal 29 to the south; and, equipment yard 30 and poles 31 to the west. The field is surrounded by roads and telephone lines on all sides. In complete darkness the on-board DGPS receiver and light bar of the present invention located the field, guided the pilot to entry point 22, computed the swath pattern, guided the pilot precisely to and along each swath, monitored position and ground speed while dispensing the pre-selected amount of fertilizer per acre, guided the pilot to departure point 32 and navigated him home. At home base, the area map 20 showing the complete actual path flown over the ground and printouts showing all of the other related flight data were printed within minutes after touchdown.

Additionally, the AirStar system is capable of providing guidance to any selected waypoint (entered into the system using latitude and longitude coordinates); displaying position, altitude, speed and heading information; informing the pilot of distances with respect to manually entered line end points; and also gives an indication of being within a defined closed area of up to 17 sides. The AirStar system assists the pilot in spraying operations by providing, for example, GPS/flux gate compass derived wind speed and direction, preprogrammed swath pattern definitions, distance to field entry and exit, real time display of the number of acres sprayed, and two programmable digital light bar displays for indication of ground speed, true heading, swath number and lateral displacement from and angle of intercept with desired swath path. The addition of the flow controller allows the AirStar system to monitor and control the spray system and display flow in gallons per acre and total gallons remaining. To facilitate post flight
analysis and provide a permanent record of spraying operations, a complete data log of time, position, altitude, ground speed, spray on/off and flow status, and wind speed and direction is recorded by the system.

b. Swathing Patterns

(1). Field Layout

As shown in Fig. 3, the AirStar system is a very versatile system capable of flying a field or spray area of any shape, and establishing parallel swaths of unlimited length.

(a). Establishing the A-B Reference Line

Once the system has been powered up and the vertical yellow-centerline lights 155 on the light bar 46 are steady (see Section 4 infra.), the system is ready to accept the definition of the A-B line ("Waiting-A" appears on the Swath Screen, see Section 3f(1) infra.), and the definition of LEFT or RIGHT for pattern layout. These definitions will be established by the pilot in flight over the field to be sprayed as described below.

First, as the aircraft approaches the field to be sprayed, the A point of Fig. 3 is entered into the AirStar system by the pilot’s aligning the aircraft with the desired reference edge of the field or area of interest and depressing the ABC Swath Advance button 68 (see Section 3e(11) infra.) on the keypad 60 exactly when the aircraft is over the beginning of the area to be sprayed.

The light bar 46 will now begin flashing all of its lights solid red, then solid green, at a frequency of several flashes per second. This flashing will continue until the B point is defined.

Next, the B point of Fig. 3 is entered into the AirStar system by the pilot’s depressing the ABC Swath Advance button 68 on the keypad 60 one time exactly when the aircraft is over the point at which spraying is be terminated.

It is not important that the vehicle remain on course between the selection of the A and B positions (while the lightbar 46 is flashing red, then green). It is only important that the vehicle be at the desired end point of the field at the precise time the ABC key 68 is pressed.

Thereafter, once the A-B line is established, the pilot merely pushes the same button (ABC Swath Advance 68) each time he finishes a swath (including the A-B line,
which is swath #1) and the system provides guidance to the next swath (as more fully described below).

(b). Specifying The Distance Between Each Swath

Once the A-B line has been defined, the computer 41, using a conventional algorithm, will calculate and lay out the rest of the field in successive, parallel, equally spaced tracks to the right or to the left as pre-defined by the pilot by inputting desired SWATH WIDTH in the Program Screen 130, and RIGHT or LEFT as desired on the Swath Screen 100 (See Section 3f(1) infra.).

Deviation from swath centerline will now be indicated on the lightbar 46 as a function of the pre-programmed lights (see Section 3f(4)(a) and 3(g) infra.), and can be seen digitally on the Swath Screen 100 (see Section 3f(1) infra.).

To provide guidance to the pilot the computer 41 numbers the swaths successively as shown in Fig. 3: The A-B line is swath #1, followed by 2, 3, 4, 5, etc.

This selection of LEFT or RIGHT must be done prior to laying down the A-B line.

(c). Navigating Between Successive Tracks

Based upon vehicle load, field shape, or other factors, the pilot may desire to fly any of several possible swath patterns. One pattern is to fly from one swath to the next in succession. Another is to skip adjacent swaths by advancing to a larger numbered swath and then returning to a lowered number swath in succession. The AirStar system allows the pilot to specify three possible spray patterns:

((1)). Back-To-Back

The back-to-back pattern shown in Fig. 4 allows the pilot to fly consecutive numbered swaths in succession. The A-B line is swath #1 followed by 2, 3, 4, 5, 6, 7, 8, 9, 10, etc. in order. This pattern is set up normally during completion of the quick-start checklist by first pre-setting Swath Width in the Program Screen 130 and then selecting Back-to-Back with the Pattern button 80 and Right or Left with the Left/Right button 70, on the Swath Screen 100. RIGHT BACK-TO-BACK is illustrated in Fig. 4.
((2)) Racetrack

The racetrack pattern shown in Fig. 5 allows the pilot to initially fly each end of a field and then alternately work from the A-B line to the middle and from the middle toward the C line (other end of the field). For the 12 swath field shown in Fig. 5 the order of flight is 1, 12, 2, 7, 3, 8, 4, 9, 5, 10, 6, 11. RIGHT RACETRACK is illustrated in Fig. 5.

This pattern is set up during completion of the quickstart checklist by first selecting Racetrack with the Pattern button 80 on the Program Screen 130, and then Right or Left with the Left/Right button 70 on the Swath Screen 100.

Next, during flight the pilot establishes an A-B line (as in the Back-to-Back example above) and then flies Right (or Left as preselected) to the far end of the field (display 90 will be showing "Waiting-C" and defines the width of the field for computer 41 by depressing the ABC Swath Advance button 68 thereby establishing point C of Fig. 5. The computer now recognizes the width of the field as the distance from the A-B Line to the C Line and divides the field into equal halves. The A-B line is swath 1, and the C line is swath 12.

On completion of spraying swath C, the pilot depresses the Swath Advance button 68 and receives guidance to swath #2, followed by again depressing the Swath Advance button 68 and receiving guidance to the swath #7, the centerline of the field. Each successive swath is alternately to the right of the A-B Line, and the centerline until the field is complete. The computer keeps track of the progress. The pilot knows the field is complete when pressing Swath Advance 68 gives guidance back to swath #2, which was previously completed.

((3.)) The Squeeze Pattern

The squeeze pattern is set up in the same way as the Racetrack pattern, i.e. Squeeze is preselected on the Swath Screen 100 when completing the quick-start checklist and then the A-B and C lines are established during flight. However, a different sequence of swaths is flown the computer 41 guiding the pilot to spray each side of a field, A-B and C, and then work each side, alternately, toward the middle. For the 12 swath field shown in Fig. 6 the swath sequence is 1, 12, 2, 11, 3, 10, 4, 9, 5, 8, 6, 7. RIGHT SQUEEZE is illustrated in Fig. 6.
The SATLOC™ AirStar™ system is a complex system, electronically. However, once the user masters the basic system setup and operating techniques, he is thereafter assured of many hours of uncomplicated flying or operating. When properly installed and programmed, the pilot only needs to set the desired swath width, type of pattern, and direction of turn after the first swath. Thereafter until the completion of the field, it is simply a matter of finding the field, using one switch (the A-B/Swath Advance button 68 which is usually on the stick) at the entry and exit points for the first swath, and the same switch to advance to the next swath, with guidance. The system gives direction of turn, keeps up with swath number, and tells the pilot how far to go to be on the swath.

2. The AirStar System Schematic

As seen in Fig.7, the AirStar system includes a round antenna 14, a whip antenna 15, a computer and GPS receiver unit 41, a radio receiver with data modem and power supply unit 42, a removable memory card 43, a keypad box 44, a cockpit display box 45, and a light bar display 46. The components are contained in custom made metal boxes connected in modular fashion by military style circular connectors to facilitate various configurations and easy component replacement. All boxes are sealed with rubber gaskets to prevent moisture and chemical corrosion of the internal electronic components.

The following sections describe in detail the various components which make up the AirStar system.

3. The AirStar System

a. Antennas

As seen in Fig. 8, the AirStar system utilizes two antennas. A round low-drag aircraft type GPS antenna 14 for detecting the satellite signals 5 in the 1.57542 GHz range (FAA C115a approved) and a 900 MHz range whip antenna 15 for receiving differential correction transmissions 6 from base 9.

b. Computer and GPS Unit

As seen in Fig. 9, the computer and GPS unit 41 includes a conventional 80386 DOS computer (not separately shown) and a conventional GPS receiver (not separately
shown) with PCMCIA solid state memory card 43. The function of this unit 41 is to receive the GPS signals 5 from antenna 14 and the differential correction signals 6 from the differential correction radio receiver 42 (described below) and antenna 15, run the parallel tracking and guidance software in conjunction with the keypad 60, display 90 and lightbar 46 (described below), and log the flight and spray operations to the PCMCIA memory card 43.

The AirStar computer, manufactured by Zytronix Inc., is a 4"x6" miniature CPU board with an 25 or 33 MHz 80386 processor and 80387 math coprocessor with two MBytes of memory. Additional devices on the main CPU card are the keyboard, two serial ports, one parallel port, a floppy disk drive and a hard disk drive. Two smaller boards (4"x3.5") attach directly on the top of the CPU board in a stacked fashion to support a PCMCIA Type 1 solid state memory card 43 interface and a GPIO card which has two additional parallel and serial communication ports and sound input and output using twelve bit A/D and D/A conversion. The PCMCIA memory card 43 contains the software program and data logs. The DOS operating system resides in a bootable read only memory chip. A color VGA screen for a moving map is easily supported by the addition of a 4"x3.5" VGA card to the existing stack and appropriate display software.

The GPS receiver in unit 41 is manufactured by NovAtel Communications Ltd. and is contained on a single 7"x4" board. This conventional high performance receiver is capable of tracking 10 satellites simultaneously and outputs position and speed information every 200 msec. The GPS receiver is a civilian narrow correlation type and with the timely GPS differential correction data supplied by data radio link 42 described below provides rover 13, 16 actual position with an accuracy within one meter. With no pre-knowledge of time or position the GPS receiver in unit 41 tracks satellites and outputs position within two minutes from power up. GPS signal re-acquisition, after loss due to shading of antenna 14 by the aerial rover 13 in steep turns, is typically under five seconds once the shading is removed.

The computer (CPU) power supply converts and filters DC voltages for the GPS receiver and PC card set. Attached to the computer power supply is an interface printed circuit board which provides connection for the rest of the AirStar system components including the power supply/radio modem 42, keypad box 44, display box 45, lightbar 46, and a VGA display.
c. Power Supply/Data Radio Receiver Unit

As seen in Fig.10, an integral part of the AirStar system is the power supply and data radio receiver unit 42. The power supply converts aircraft or other vehicle power 47 to meet the specific requirements of the operating components. The data radio receiver (not shown separately) is typically a 450 or 900 MHz data radio which receives the differential correction signals from base 9 via antenna 15. Unit 42 provides the data links 48,49 through which differential correction data, spray system data, wind direction and velocity data, and other monitor and control data is routed.

The AirStar’s main power supply 42 converts 18-40 volt DC aircraft voltage to 5, 12 and -12 volts DC for the various electronic sub-systems. This unit is fully protected by a crowbar type fuse circuit and a 7.5 amp blade type fuse.

The modem (not separately shown) portion of the data radio receiver uses conventional forward error correction ("FEC") technology to extend the effective range to which data integrity is maintained. As one who is skilled in the art knows, mobile communication signals increasingly fade with distance from the transmitter due to destructive interference known as "multipath fading", and the effective range can be increased by the FEC technique of introducing redundant information into the data stream combined with interleaving. Applicant's unique FEC code introduces 50% overhead (redundant information and interleaving) which lowers the net data rate to 66.6% of the channel rate and satisfactorily extends operating ranges to 100 or more kilometers.

The radio interface in unit 42 is capable of supporting two-way AirStar specific position and other data transmitting and receiving. This feature allows both messaging and addressability type receiving of special data from a central dispatch office. The position reporting feature is particularly useful for real time tracking purposes.

Additional interfaces connected in the power supply unit 42 and routed to the CPU 41 via the GPIO cable 49 include the spray on/off sensor, the flux gate compass, the spray sentinel flow control device, and a special line endpoint/swath advance switch which is usually mounted on the pilot's joystick. GPS data output is available for future expansion of the AirStar functions if necessary. Twelve volt and five volt DC power are also available for the flux gate compass and the spray sentinel respectively.
d. PCMCIA Memory Card

As seen in Fig. 11, a 2-megabyte, PCMCIA card 43 is included as standard equipment with each AirStar system. Cards with increased memory capacity are available as options. Cards are not interchangeable between AirStar units.

e. The Keypad Box

As seen in Fig. 12, the keypad box 44 is a housing for a custom 4x5 key matrix with a single labeled membrane. Additional devices mounted on the keypad box 44 are the main system on/off switch 51, a headphones jack 52 for sound output, rheostat 53 for keypad 60 backlighting and display 90 brightness, rheostat 54 for lightbar 46 lights 151, 153, 156, 157 and digital outputs 156, 157 brightness, rheostat 55 for audio output volume and a twenty button keypad 60 for setup and operation of the system.

The twenty button keypad 60 controls:

- Screen selection (SWATH, NAVIGATION, GPS SATELLITE, PROGRAM, WAYPOINT),
- Functions (Home, Pattern, Clear, etc.),
- Alpha and numeric entry to the WAYPOINT and Program Screens i.e., swath width = 48, or Waypoint 3-letter/number identifier (SAT), and
- Spray Sentry control 170.

The keypad 60 incorporates the ability to manage the many functions of the system. The basic functions required for successful use in flight are programmed prior to take-off. The operation in flight is reserved to one or two keys, most of which can be incorporated into the pilot’s stick grip.

For example, the pilot programs swath width and lightbar settings on the ground. On take-off the pilot flies to the desired entry point. Upon arrival at the field to be sprayed, the pilot evaluates the wind conditions and then programs the type of pattern and the right or left direction of progression from the A-B Line. He squeezes the trigger switch (function of ABC/Swatth Advance button 68 on keypad 60 can be programmed into the pilot’s stick grip) on the stick grip to set point A, the same switch to set point B, and the same switch to advance to the next swath.

When the field is done, the pilot simply hits the CLEAR/RESET button 76 on the keypad 60 and starts a new field, just as above. If a different pattern is required, he
toggles the PATTRN switch 80 on the keypad 60 and toggles the Left/Right switch 70 for right or left direction of turn.

The operational logic of the Keypad 60 which control inputs to computer 41 is as follows:

1. The numerical/function keys 65-67, 69-71, 73-75, 78 (numbered 1, 2, 3, 4, 5, 6, 7, 8, 9, 0) enter numbers in data/numeric blocks when in the Program Screen, i.e. Swath Width = 40, or the Waypoint Screen, e.g. WayP-LAT = 32 17.0000.

2. The numerical/function keys 65-67, 69-71, 73-75, 78 (the functions Home, Plot, Mark, Left/Right, Dim, Save/Purge, Return, Route) enter functions in the Swath Screen, i.e. pattern direction = LEFT, and Navigation Screen, i.e., HOME = range and bearing to home.

3. The function keys 68, 72, 76, 77, 79, 80 (the functions ABC ADV, DECR, CLEAR/RESET, SCREEN/ENTER, WPT, PATTERN) have specialized/multiple functions to be discussed below.

The function of each control on keypad box 44 and of the twenty buttons on keypad 60 shown in Fig. 12 are described below:

(1). On

The switch 51 on the upper left corner of keypad box 44 toggles power to the system on and off.

(2). Phones

The phones jack 52 is located below the power switch 51 and is used to plug in the headphone connection when audio output is installed.

(3). Rheostats

The KEYPAD and LIGHTBAR rheostats 53, 54 respectively control the brightness of keypad 60 and lightbar 46 lights. The AUDIO rheostat 55 adjusts headset volume when audio output is installed.

(4). Set

SET button 61 sets Spray Sentry 170 Operation when installed. If installed, the
SET button is used to save entries which are made in the View button 62 menu. If pressed in any other mode the display 90 reads:

SET Feature.
Only valid in VIEW mode.
Any Key To Continue.

(5). View
View button 62 enables viewing Spray Sentry 170 Operation data when installed. When VIEW button 62 is depressed, the display 90 reads:

GAL TOTAL 000
GAL/ACRE 00.0000
GAL/MIN 000.0
COUNTS/GAL 440.0 AC/PASS Y/N Depress SWATH
button 64 to exit.

(6). Repeat
Repeat button 63 repeats Spray Sentry 170 Operation when installed. If not installed, when the Repeat button 63 is depressed, the display 90 reads:

REPEAT Feature
Not Installed
Any Key To Continue

(7). Swath
SWATH button 64 may be pressed at any time to return to the Swath Screen.

(8). 1/Home
Depressing 1 button 65 enters the number 1 in the SPRAY SENTRY 170, PROGRAM or Waypoint Screens.

The first depression of the HOME button 65 after turning the system on causes the current aircraft position (latitude and longitude to the ten thousandths of a minute, i.e., 32.54.2367) to be stored as the home point in Waypoint 1 in route 11 (see WAYPOINT and ROUTE infra.) over-writing any values previously entered. Any
subsequent depressions of this key while in the SWATH or Navigation Screens will give Range (Swath Screen) and Range/Bearing (Navigation Screen) to the home point.

Additionally, if no swath pattern is in progress or if the CLEAR button 76 is depressed to clear the pattern which is in progress, the lightbar 46 will provide guidance to the home point. If you want to save the pattern for return after loading, first press MARK button 69 to mark the spot for return and then press CLEAR. The lightbar 46 guidance to home point may be used. After loading, depress the RETURN button 75 and the marked pattern will be displayed for return to the field.

If the system is powered down, a new cycle is initiated, i.e., the existing home position is lost, and a new home position is stored with the next selection of the HOME button 65.

(9). 2/Plot

Depressing the 2 button 66 enters the number 2 in the SPRAY SENTRY 170, PROGRAM or Waypoint Screens.

Depressing the PLOT button 66 toggles between PLOT ON and PLOT OFF. The system is programmed to optionally log vehicle navigation data for use in subsequent post flight software processing. The PLOT key 66 places an identification flag in the logged data that is time tagged and located via GPS. This flag continues to be set in the data record until the PLOT key 66 is depressed a second time. This flag is also used to mark the duration of an event i.e., when the vehicle spray system is on. The status is indicated by *SP* in the bottom row of the Swath Screen in place of ---. This function may also be controlled remotely by the spray pressure system which may also be wired for automatic logging of the spray event.

(10). 3/Poly

Depressing the 3 button 67 enters the number 3 in the SPRAY SENTRY 170, Program or Waypoint Screens.

Depressing the POLY key 67 records a point in a polygon into memory. The pilot may define an area by pushing this button up to 17 times. When 3 or more points have been stored, the computer draws a polygon. Each time the aircraft enters the area the green AREA light 94 on the right side of the display 90 illuminates. The light 94
extinguishes upon exiting the area.

An existing polygon is cleared by entering and then exiting the Waypoint Screen.
A new polygon may be initiated by pushing the POLY key 67 again. Only one polygon can be stored at a time, and any point beyond 17 replaces the prior point 17.

(11). ABC ADV/UP Arrow

Button 68 sets the A-B Line and the C Line, advances the swath number, and provides an arrow function which (1) scrolls upward in the Program Screen, and which (2) changes values which are toggled.

Once the GPS system has reached the operational status signified by the display of the message "WAITING-A" on the Swath Screen pressing the ABC/ADV key 68 causes the aircraft current location to be stored as the "A" point in the swathing program. The "A" point is defined by the ABC ADV key. Regardless of which swathing pattern has been selected, this key will be interpreted as point "A" the first time it is depressed while initiating a spray pattern.

Pressing the ABC ADV key 68 the second time will cause the aircraft location in the field at the time the key 68 was pressed to be stored as the "B" point in the swathing algorithm.

When RACETRACK or SQUEEZE has been selected as the swathing pattern and the "B" point has already been established, pressing this key 68 a third time will cause the aircraft location at the time it was pressed to be stored as the "C" point. Generally speaking, the A-B Line is one edge of a field, while "C" point defines the other edge.

When the "C" point is selected, the program gives guidance to the next swath centerline outside C. For example, let us assume that the pilot has flown the A-B Line and has then entered the edge of the field, i.e., the C line. By looking at the amount of swath offset in left window of the lightbar 46, the pilot can see how many feet it is to the outside swath centerline and decide whether or not to make the next pass on an inside swath centerline.

The ABC ADV key 68 is also used to advance to the next swath after the A-B Line in the Back-to-Back pattern, and after point C in the RACETRACK OR SQUEEZE patterns have been established. The system defines the A-B Line as swath #1. In the Back-to-Back pattern, successive depressing of the ABC/ADV key will select swath 1,
2, 3, etc. In the RACETRACK or SQUEEZE patterns, the ABC ADV key 68 is used to define the A-B Line, then to establish the width of the field (C Point). Subsequent depressing of this key will then provide guidance to a sequence of swaths based upon the total number of swaths calculated to be in the field (the perpendicular distance from the A-B Line to Point C divided by swath width). The system logic divides the field into halves and provides sequential overlapping race-track-like guidance (see Figs. 3-6).

The Up Arrow 68 is functional ONLY in the Program and Waypoint Screens. At that time it functions as follows:

In the Program Screen it performs 3 functions:

1. Cycles thru alphanumeric characters, e.g., A, B, C, 1, 2, 3, etc. and symbols, e.g., #, etc. for entry into data blocks, e.g., Pilot's Name.
2. Changes value, e.g., Lightbar Brightness: Bright, Medium or Dim.
3. Scrolls to previous entry, or backward in the options list. To scroll backward from lightbar brightness setting, for example, the pilot must use the Left Arrow 79, as the Up or Down Arrow merely changes the intensity level. Push ENTER to accept the setting and move to next data entry block.

(12). 4/Mark

Depressing the 4 button 69 enters the number 4 in the SPRAY SENTRY 170, Program or Waypoint Screens.

When the user wishes to record current position and swathing status to later return to a precise point in the field, the MARK key 69 should be depressed. This action stores to memory card 43 all current operational data, such as, A-B Line, type of pattern, direction of turn (right or left), swath #, and exact current position. This data can be recalled either before or after shutdown and restart by pressing RETURN. The system looks in its database for a point previously recorded as a mark. If it finds such a point, the system gives the range and bearing to return to it and, if MARK key 69 was selected while in a spray pattern, restores the status of the spray/swathing session as it was when the mark was saved. Depressing MARK key 69 will override any previously saved MARK data.
(13). **5/Left-Right**

Depressing the 5 key 70 enters the number 5 in the SPRAY SENTRY 170, Program or Waypoint Screens.

Before the operator defines the A-B reference line for subsequent swathing, the pilot must decide if the aircraft will be operated to the RIGHT of the A-B line or to the LEFT. If the LEFT key 70 is pressed while the system is displaying "Waiting for A", the screen will display LEFT. Depressing the LEFT key 70 toggles between LEFT and RIGHT. The RIGHT key 70 is for selecting the Program Screen. If LEFT is selected, the system will lay out a grid of 999 lines to the left of the A-B reference line. If the operator desires to change the RIGHT/LEFT setting after the A-B line has been defined, the CLEAR/RESET key 76 must first be pressed, then the LEFT key 70 toggled to select LEFT or RIGHT as desired and then the A-B line reinstalled.

(14). **6/*

Depressing the 6 button 71 enters the number 6 in the SPRAY SENTRY 170, Program or Waypoint Screens.

Press the * button 71 to enter the Program Screen.

(15). **DECR/Down Arrow**

Depressing the DECR button 72 decreases the swath number from that currently selected (opposite of ADV). This function is useful in that the pilot may advance swaths, say from 2 to 10, in order to avoid personnel in the field, and then decrease swath from 10 to 3 to resume the previous position. This button is also used to decrease swath number when pilot inadvertently advances more than one swath with the ADV (swath advance) button 68.

The Down Arrow button 72 functions ONLY in the Program and Waypoint Screens. In the Program Screen it performs 2 functions:

1. Cycles thru alphanumeric options, e.g., A, B, C, 1, 2, 3, etc. and symbols, e.g., #, for entry into data blocks (opposite of Up Arrow), i.e., Pilot’s Name.

2. Changes or toggles value from built in default list e.g. Differential correction format may be set to DCSA or RTCM.
(16). 7/Dim

Depressing the 7 button 73 enters the number 7 in the SPRAY SENTRY 170, Program or Waypoint Screens.

To support night operation the DIM key 73 reduces the intensity of the display 90. Each depression reduces the brightness approximately by 30%. The fourth depression cycles the display 90 back to its brightest setting.

(17). 8/Save/Purge

Depressing the 8 button 74 enters the number 8 in the SPRAY SENTRY 170, Program or Waypoint Screens.

The AirStar™ system automatically logs flight/spray data as determined by the settings in the Program Screen. Depressing the SAVE/PURGE key 74 displays 3 options and one message as follows:

1. SAVE - New Log File. If SAVE is selected, the following dialogue appears in the window:

"New Log Opened, Press any key..."

2. CLEAR - Purge Files. If CLEAR is selected, the following dialogue appears in the window:

"Log Files Purged. New Log Opened.
Press any key..."

3. ENTER - Exit. If ENTER is selected, the Swath Screen comes up. No change has been made, i.e., the log file has not been purged and logging will continue automatically on the existing file.

4. Also, the message "Mins Left 1020" appears at the bottom of the screen and indicates how many minutes of operation can be logged before filling the memory card 43.

(18). 9/Return

Depressing the 9 button 75 enters the number 9 in the SPRAY SENTRY 170, Program or Waypoint Screens.

If it is desired to return to the same point in a field and resume the swathing operation, the pilot must first install the desired return point by pressing the MARK key
69 at the point where the swathing operation terminated and then press the RETURN key 75 to get range, bearing and guidance back to that point.

Whenever desired, even after turning off the power to the system, pressing the RETURN key 75 will cause the system to restore the program status to the state at which it was when the MARK key 69 was pressed. At this time, the lightbar 46 displays the distance off the desired track toward the marked point.

(19). **Clear/Reset**

In the menu mode, the CLEAR/RESET key 76 serves as a delete key for items entered into the various program options.

Pressing CLEAR/RESET key 76 will reset the computer swathing program irrespective of whether the aircraft is currently swathing. It removes all reference to the A-B line, and the current swath, as well as the display of cross track error on the light bar 46. When reset, the system displays solid yellow in lightbar 46 lights with no RED/GREEN lights irrespective of cross track error status. Once the RESET key 76 is used, the A-B reference line, the direction RIGHT or LEFT of swath, the swath PATTERN, and the SWATH WIDTH can all be reinputted. As stated above the proper procedure for swathing is to select PATTRN and LEFT OR RIGHT and check that the desired Swath Width is set prior to commencing to establish the A-B Line.

Inadvertent selection of the LEFT/RIGHT key 70 or the PATTRN key 80 will not clear the current pattern if swathing. During normal swathing operations the only way to "dump" the existing pattern is to press the CLEAR/RESET button 76.

(20). **Screen/Enter**

The SCREEN/ENTER key 77 has two functions: (1) to cycle through the Swath, Navigation, GPS Satellite Screens, and (2) to advance between data entry blocks in the Waypoint and Program Screens.

To change screens, simply push SCREEN key 77 and cycle through Swath, Navigation, GPS Satellite. This action will not destroy any current swathing pattern.

The ENTER function of key 77 is operable in the Waypoint and Program Screens. It is used in the same way that the ENTER key on a computer keyboard is used. Once a value has been selected for an option, or a selection from an option item has been
implemented, the ENTER key 77 is depressed one time to input that value to the
computer 41.

In order for a new value to be used by the program, it must be ENTERED prior
to exiting the Program Screen.

(21). O/Route

Depressing the O button 78 enters the number O in the SPRAY SENTRY 170,
Program or Waypoint Screens.

The AirStar™ system incorporates a complete point-to-point navigation system.

It is structured in routes and waypoints.

The Route button 78 is functional when the Waypoint Screen is displayed, and
when the button is depressed while in the Navigation Screen.

The system can accommodate up to 12 preprogrammed routes, each containing
10 waypoints. Routes 1 thru 10 are available for the pilot to store up to 100 latitude and
longitude positions. Route 11, Waypoint 1, contains the Home function. Route 11,
Waypoints 2 & 3, are used for programming a remote A-B line. Route 11, Waypoints
4 thru 10, and Route 12, Waypoints 1 thru 10, are reserved for the 17 points of the
polygon.

(22). WPT/Left Arrow

A waypoint is a specific latitude and longitude position which is programmed by
the operator into the Waypoint Screen. There are 10 available slots or entries in each one
of the 12 Routes, for a total of 120 possible entries.

Depressing the WPT button 79 while in the Swath or Navigation Screen selects
the Waypoint Screen. While in the Waypoint Screen, the WPT button 79 scrolls through
slots 1 thru 10, and then back to 1. The example in Fig. 13 F shows Route 01, WayP
(Waypoint) 03, ID (identification) SAT, and a specific latitude and longitude.

Referring to Fig. 13F the normal operation in the Waypoint Screen using the WPT
key 79 is as follows:

1. Depress the WPT key 79.

2. Select the desired Route (by depressing ROUTE button 78, also a 1-10
rolodex function).
3. Select the desired waypoint to be programmed by successively depressing the WPT button 79 until the desired waypoint number appears in the upper right-hand corner of the screen.

4. Enter a three-letter, or three number identifier, e.g., SAT, or 123, in the spaces to the right of the designation WAYPT in Fig. 13F. The letter O may be used, but ZERO is not permitted in naming ROUTES or WAYPOINTS.
   a. Scroll to each successive data block by depressing the ENTER button 77.
   b. To return to a previous entry, continue depressing the ENTER button 77, or, use left Arrow button 79.

If no station identifier is desired, the ENTER key 77 or the DOWN ARROW key 72 must be pressed until the blinking cursor is on the first item of the latitude block.

5. At this point the numeric keys are used to enter the latitude in degree-minute-seconds format. A negative latitude is specified by toggling the N(North)/S(South) digit displayed in the Waypoint screen at the end of the latitude block with the UP/DOWN Arrow keys 68,72, respectively, as appropriate.

6. The longitude is entered in the same fashion when the blinking cursor is on the longitude field.

7. To exit from this menu, the user must press the SWATH key 64. Pressing the SWATH key 64 selects the last valid Waypoint and Route for display in the RANGE and BEARING fields of the main display screen (i.e., the swath screen).

The LEFT ARROW key 79 permits the user to back the cursor through item selections in MENU or NAVIGATION/WAYPOINT modes.

Routes 1 thru 10, and their 100 waypoints can be used for any field, airport, or navigation point the pilot selects. Thus, in addition to parallel track navigation, the system provides for vehicle navigation over the earth. This feature can be used to select a set of pre-defined courses or routes. To organize the courses, the system allows 10 Waypoints consisting of latitude and longitude to be defined for each of 10 separate Routes. The Routes can be used to collect a certain set of Waypoints that are related, e.g., as many as 10 fields could be entered as Waypoints in NORTHERLY-Route 1. In addition, 10 in SOUTHERLY-Route 2, etc.
(23). **PATTRN/Right Arrow**

The PATTRN key 80 toggles between the BACK-TO-BACK, RACETRACK, and SQUEEZE patterns. The system will always boot up in the RIGHT BACK-TO-BACK pattern.

The RIGHT ARROW key 80 is not functional at this time.

**f. The Display Box**

As seen in Fig. 13A, the display box 45 of the AirStar™ system houses a 20x4 character vacuum florescent Noritake display 90 for status, operator control, and data input. The display 90 is green and has software controlled brightness levels which make it suitable for night spraying. Also included in the display box 45 are four separate light emitting diodes ("LED") 91-94 which, when ON, indicate the following (from left to right in Fig. 13A):

<table>
<thead>
<tr>
<th>NAME</th>
<th>COLOR</th>
<th>MEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYS 91</td>
<td>GREEN</td>
<td>POWER ON</td>
</tr>
<tr>
<td>GPS 92</td>
<td>RED</td>
<td>GPS INVALID</td>
</tr>
<tr>
<td>DIFF 93</td>
<td>AMBER</td>
<td>DIFFERENTIAL INVALID</td>
</tr>
<tr>
<td>AREA 94</td>
<td>GREEN</td>
<td>INSIDE POLYGON</td>
</tr>
</tbody>
</table>

As seen in Figs. 13B-13F the four-line digital display 90 provides information to the pilot through five separate screens 100, 110, 120, 130, 140, the first three 100, 110, 120 of which cycle sequentially (one-way rolodex), and the next two 130, 140 of which are selected by pressing specific keys as follows:

- Swath Screen 100 (Fig. 13B)- is automatically displayed on start-up. Press the SCREEN/ENTER button 77 to scroll to the Navigation screen.

- Navigation Screen 110 (Fig. 13C)- is the second screen in sequence. Press the SCREEN/ENTER button 77 to scroll to the GPS Satellite screen.

- GPS Satellite Screen 120 (Fig. 13D)- is the third screen in sequence. Press SCREEN/ENTER button 77 to scroll back to Swath Screen 100.

- Program Screen 130 (Fig. 13E)- is the fourth screen. Press the * button 71 to enter this screen. Press SWATH button 64 to exit to Swath Screen 100.

- Waypoint Screen 140 (Fig. 13F)- is the fifth screen. Press the WPT button 79 to enter this screen. Press the SWATH button 64 to exit to Swath Screen 100.
(1) **SWATH SCREEN**

As seen in Fig. 13B, the swath screen is automatically displayed on start-up, or anytime the Swath button 64 is depressed. Press the Screen/Enter key 77 to advance to next screen.

The Swath Screen is the first screen to be displayed after the system is powered up, and Built-In-Test/GPS Initialization is completed. With the system properly programmed (via the Program Screen 130), all the information necessary to spray a field, with parallel tracking & guidance is displayed. The screen has three possible formats of data blocks:

1. The format which comes up prior to a full GPS solution, i.e., 3 or more satellites (as shown in Fig. 13B),
2. The "Waiting-A" format, which indicates a GPS solution has been obtained and the system is ready for the pilot to select an A-B Line (discussed below), and
3. The "Swath-001" format which means a swathing pattern is in progress (discussed below).

The following data blocks and definitions refer to the format which appears at start-up and as seen in Fig. 13B:

- **"RGHT"** means the direction of progression of pattern (left or right of the first swath [left is an option]) after first swath in a pattern. The LEFT/RIGHT key 70 toggles selection between RIGHT or LEFT.
- **"BK-BK"** means the Pattern selected. The PATTRN key 80 toggles selection between options: Back-To-Back, Squeeze, Racetrack.
- **"WAIT-GPS"** means the system is waiting for a GPS solution, i.e., 3 or more satellites received. The GPS receiver uses corrections, last received, for up to one minute.
- **"OFF R 0000"** means the distance, in feet, and direction to the centerline of the swath. Inoperative unless swath pattern is in progress.
- **"WD 000 00 "** means the data block for wind direction & speed
- **"TRK 000"** means the true track of the aircraft in degrees.
- **">A 0003" or ">3 0002"** means the distance in feet to point
A or B for each swath.

"RG 0000"
means the range in miles, changing to feet inside one-mile, to home, selected waypoint, or mark after selecting RETURN 75 if MARK/RETURN function has been initiated.

In the second possible format in Swath Screen 100 described above the "WAIT-GPS" display of the first format changes to "WAITING-A" which means a GPS solution and ready for pilot to initiate an A-B Line for parallel tracking 3 and swathing. All other data blocks remain the same, except that values for WD, TRK and RG (if Home, Waypoint, or Return to Mark has been selected) will appear.

(2). NAVIGATION SCREEN

As seen in Fig. 13C this is the second screen in the sequence. Press the Screen/Enter key 77 to enter from the Swath Screen or to select next screen. The Navigation Screen 110 provides current position in latitude (LAT) and longitude (LON) (assuming a GPS solution), selected route and waypoint, groundspeed, ground track, bearing to selected route/waypoint, altitude, and range to selected route/waypoint. The example in Fig. 13C illustrates GPS received; otherwise, all values would be 0. The terms displayed mean as follows:

LAT  Current Latitude in degrees, minutes, 1/10,000 of a minute and North (N) or South (S). Valid only if GPS OK. (degree = 60 nm, minute = 1 nm, .0001 minutes = 18 cm)

RT   RT 01 indicates route 1 selected (ROUTE key 78). There are 12 routes with 10 waypoints in each route.

LON  Current Longitude in degree, minutes, seconds, and East (E) or West (W). Valid only if GPS OK.

W    W SAT indicates a Waypoint which the pilot has defined and identified by the three letter identifier SAT, which is selected by WAYPOINT key 79. There are 10 waypoints in each of 12 routes.

SP   SP 120 indicates 120 mile-per-hour groundspeed. Valid only if GPS received.

TK   TK 317 indicates True Track over the ground of 317 degrees.
BG 359 indicates True Bearing to selected Waypoint, Mark, or HOME in degrees.

ALT 00319 indicates height above a spheroid earth, (approximately mean sea level (MSL) in feet). If less than 4 satellites received, the system defaults to value entered in Program Screen.

RG 0025 indicates distance in statute miles to selected Waypoint, HOME, or MARK. When the range is less than 0.19 miles (1000 feet) the display 90 reads out in feet.

(3). GPS SATELLITE SCREEN

As seen in Fig. 13D, this is the third screen in the sequence. Press the Screen/Enter key 77 to enter from Navigation Screen. Press Screen/Enter key 77 to select next screen.

The GPS Satellite Screen provides information on time, date, satellites, degree of precision, GPS status, and bit test status.

T GMT corrected by the time offset entered in the Program Screen: hours, minutes, seconds. Available regardless of GPS solution status.

D Current Date: day, month, year. Available regardless of GPS solution status.

SV Number of satellites seen by the GPS receiver, but not necessarily entered into the GPS solution. Those satellites in the GPS solution are listed below, up to 10 satellites, i.e., 21 03 17 09, etc. A minimum of 3 are required for SL OK, and 4 for altitude.

MA Mask Angle, as entered in the Program Screen, SV Mask Angle.

DOP Dilution of Precision. An index number which indicates the degree of accuracy of the current GPS solution. The lower the number, the better the accuracy. Generally, 4 or less will give very good tracking performance.

DF Indicates time since last differential correction received. Normally O to 5.

BT Indicates status of built-in-test (BIT) sequence, not significant to user if system operation properly. If other than OK, note code for technical brief.
(4). PROGRAM SCREEN

As seen in Fig.13E the user presses the * key 71 to enter this screen from Swath, Navigation or GPS Satellite Screens. The user must press the Swath key 64 to exit this screen.

The Program Screen 130 is for entering essential information for system operation. Once programmed (normally in preflight) most entries need not be changed again.

(a). Programming AirStar

The following programmable options are displayed in the Program Screen 130:

Swath Width 090 ft. The Swath Width is the width in feet of the desired spray pattern and is operator selectable, depending on the chemical and type of aircraft/equipment. To enter swath width, type in the number, i.e., 70 for a seventy foot swath, and then press Screen/Enter key 77 to accept the entry and scroll to the next item.

Log Interval 02 sec. The Log Interval determines the frequency of updates to the log file which is saved to the PCMCIA card 43. A setting of 99 disables the logging function. To enter Log Interval, type in the number, i.e., 02, and then press Screen/Enter key 77 to accept the entry and scroll to the next item.

Log Speed 50 mph. The Log Speed is the speed, in statute miles per hour (ground speed) at which the system begins to log the flight path information. If track information from take-off to landing is required, set take-off ground speed or less. Otherwise, set lowest ground speed associated with the spray operation. To enter Log Speed, type in the number, i.e., 90, and then press Screen/Enter key 77 to accept the entry and scroll to the next item.

SV Mask Angle 05. The SV Mask Angle is the angle from the aircraft to a point in degrees above the horizon within which satellites are not used for positioning. This helps to reduce the probability that a key satellite will drop below the horizon during tracking operations. A setting of 5 is normal. In rugged terrain, with varying terrain, consider selecting a higher mask angle.

GMT Offset 00 hrs. Enter 5 for Eastern Standard Time Zone, 6 for Central, 7 for Mountain, 8 for Pacific. Subtract 1 for Daylight Time where applicable. Arizona, for example, remains the same all year. To enter GMT Offset, type in the number, i.e., 6, and then press the Screen/Enter key 77 to accept the entry and scroll to the next item.
GMT Hemisphere >WEST. Toggle the Up Arrow key 68 or the Down Arrow key 72 to East or West as required, and then press Screen/Enter key 77 to accept the entry and scroll to the next item.

3 -SV Alt 000 ft. Enter altitude (usually local area or airport). This altitude (default) will be displayed in the ALT window of the Navigation Screen when the system is receiving less than 4 satellites. Three satellites are required for GPS solution. Press Screen/Enter key 77 to accept the entry and scroll to the next item.

Remote AB ON/OFF. Remote AB ON allows the pre-entered Waypoints, i.e., Route 11 Waypoints 2 and 3, to pre-define an A-B line for a field prior to entry, given that the latitude and longitude for A and B are known. Upon selecting ON and exiting to Swath Screen 100, guidance is displayed to the field/A-B line. To change the setting toggle the Up Arrow key 68 or the Down Arrow key 72 and then press Screen/Enter key 77 to accept the entry and scroll to the next item, or press Swath key 64 to exit to Swath Screen 100.

Lightbar Display >ANG or >SW#. With the dual row Lightbar 46 if intercept angle (">ANG") is selected and, for example, +089 is displayed in the right window on lightbar 46, it means that the angle of intercept is 89 degrees and the swath is to the right (+is right and - is left). Conversely, if -089 is displayed, it means the intercept angle of 89 degrees and the swath is to the left. If swath number ("SW#") is selected, swath # is displayed in the right window on lightbar 46. To change the setting toggle the Up Arrow 68 or the Down Arrow 72 and then press Screen/Enter key 77 to accept the entry and scroll to the next item.

Lightbar Angle 05. This setting is the angle in degrees preprogrammed for each light on the lower lightbar. A 5 degree setting would give values of 5 thru 75 degrees for lights 1 thru 15. (See Section 3g infra.). An entry of 99 will disable the lower lightbar, but the upper lightbar will still provide normal functions. To set the light value enter the desired numerical value and then press Screen/Enter key 77 to accept the entry and scroll to next item. The following is an example only. Individual settings for each light are pilot preference.

Light # 01 0003 ft or 0002
Light # 02 0006 ft or 0004
Light # 03 0009 ft or 0008
Light # 04 0012 ft or 0016
Light # 05 0015 ft or 0032
Light # 06 0018 ft or 0064
Light # 07 0021 ft or 0150
Light # 08 0024 ft or 0250
Light # 09 0027 ft or 0350
Light # 10 0030 ft or 0450
Light # 11 0033 ft or 0600
Light # 12 0036 ft or 0750
Light # 13 0039 ft or 0900
Light # 14 0042 ft or 1050
Light # 15 0045 ft or 1200

In the above example each option 1 thru 15 is a setting for a light pair, i.e. one left and one right of the center column of lights of the lightbar 46 (the swath centerline). In the example above, Light #01 is the first light each side of center, and "0003" represents a 3 ft deviation. Each light pair can be individually set to any value up to 9,999 feet based on user experience and preference. Another example is described with reference to Fig. 15, infra.

Job ___________. The job name or number may be entered using up to 10 digits by toggling the up Arrow key 68 or the Down Arrow key 72 and the Screen/Enter key 77 between each digit. By selecting SAVE after each job the pilot starts a new file, which can be annotated by going to the Program Screen and changing the job number.

Pilot ___________. The pilot name or number may be entered using up to 10 digits in the same manner as described above for the job number.

Aircraft ___________. The aircraft name or number may be entered using up to 10 digits in the same manner as described above for the job number.

Temperature 000. Enter numerical digits and press Screen/Enter key 77 between digits to accept entry and scroll to next item.

Rel Humidity 000. Enter numerical digits and press Screen/Enter key 77 between digits to accept entry and scroll to next item.

Baro Pressure 00.00. Enter numerical digits and press Screen/Enter key 77 between digits to accept entry and scroll to next item.
DGPS Format >DCSA. Toggle between DCSA or RTCM, depending on Differential Correction System by toggling Up Arrow key 68 or Down Arrow key 72 and then press Screen/Enter key 77 to accept entry and scroll to next item.

Recall Fld. A Y/N option is provided. If "Y" is selected, the previous swathing pattern is automatically displayed if it had been "marked." In order to allow a user to eliminate the swathing pattern, selecting "N" will allow multiple Mark key 69 /Return key 75 sequences, with Clear key 76 between each sequence, without recalling a previous pattern. This will allow unobstructed range, bearing, and guidance to any point "marked". As a safety precaution, any previously "marked" pattern can be returned to by entering the Program Screen 130 and reselecting "Y" followed by the Return key 75 after re-entering the Swath Screen 100.

(5). WAYPOINT SCREEN

The User must press the WPT key 79 to enter this screen from the Swath, Navigation, or GPS Satellite Screens and must press the Swath key 64 to exit.

As seen in Fig. 13F, the Waypoint Screen 140 is used to enter the ID and latitude and longitude of a Waypoint (field, airport, navigation fix, etc.). It is used in conjunction with the ROUTE key 78 and the WPT key 79 in order to select a specific route/waypoint for a new entry, or navigation based on a previously programmed position.

Simply select the screen, select or enter a waypoint, then exit to the Navigation Screen 110 for full navigation information relative to the selected waypoint, or to the Swath Screen 100, if desired, for continuing spray operations. As seen in Fig. 13F:

ROUTE 01 is 1 of 12 routes which can be selected by scrolling with the ROUTE key 78.

WAYPT 03 is 1 of 10 waypoints available in each route, and is selected by scrolling with the WPT button 79.

WAYP ID SAT is the three-letter, alphanumeric identifier for the Waypoint.

Entry into the Waypoint Screen 100 during a swath pattern will not result in the swath being decreased and "frozen" at swath 1 upon exit from the Waypoint Screen.

g. The Lightbar

As seen in Figs. 14A-F the AirStar™ lightbar 46 consists of 63 LED’s arranged
in two rows each with 15 red lights 153, 154 on the left and 15 green lights 151, 152 on the right. Three vertically arranged yellow lights 155 in the center are used to indicate when the aircraft is on track. The top row of 30 lights 151, 152 and bottom row of 30 lights 152, 154 are used to guide the pilot on track by indicating cross track error in feet and angular deviation in degrees from the desired spray line track. As mentioned earlier, two banks of large 4 digit 7 segment numerical displays 156(right), 157(left) one on each side of the two rows of LED's are programmed to display various information to the pilot (e.g., swath number). Brightness is controlled by the keypad rheostat 54.

The lightbar of the present invention significantly enhances readability of the lightbar lights and symbols which is most noticeable in high ambient light conditions. When the sun is shining directly into the lightbar, the present invention improves performance from unusable to very readable. Lightbar 46 uses a conventional circular polarizing material from Polaroid as the display window 158. The material is constructed from a linear polarizer that is laminated to a 1/4 wave optical retarder plate 158a. The use of this material allows ambient light to enter the lightbar 46 display area, but does not allow odd order reflections (most of the reflected or back scattered light) to escape. It does, however, allow display light to escape with only a small amount of attenuation. The circular polarizing window 158, 158a is combined with a mounting configuration that further enhances the display performance. The display window 158, 158a is mounted at an angle to the shaded interior roof 159 of the lightbar shroud which provides as the first surface reflection, a reflection of the dark roof 159 of the lightbar shroud which is not visible. The effect is so good that users reach out to touch the display window 158, 158a to be sure there is really one there.

The lights 151, 152, 153, 154 have the following meanings:

<table>
<thead>
<tr>
<th>LIGHT</th>
<th>COLOR</th>
<th>MEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Lights</td>
<td>Horizontal RED</td>
<td>Turn Left Into Lights</td>
</tr>
<tr>
<td>Center Lights</td>
<td>Vertical YELLOW</td>
<td>On Centerline Of Swath</td>
</tr>
<tr>
<td>Right Lights</td>
<td>Horizontal GREEN</td>
<td>Turn Right Into Lights</td>
</tr>
</tbody>
</table>

The Lightbar 46 is a single unit designed to be internally or externally mounted. When externally mounted on the engine cowling, for example, the pilot can see the lightbars with just his peripheral vision. It provides information to the pilot for tracking,
guidance, angle-off-swath, rate of closure on or departure from swath, swath #, and distance off-swath by means of the two independent, horizontal rows of lights 151,153,152,154 and the two digital readouts 156,157 located at each end of the lightbar.

The left digital window 157 provides distance in-feet left or right of the aircraft to the swath centerline. Thus, to get to the swath centerline, the pilot must always "fly into the lights". L032 in display 157 of Fig. 14A tells the pilot that a correction left 32 feet to centerline is required. A read-out of R166, for example, tells the pilot that a correction to the right of 166 feet is required.

The right digital window 156 provides two options:
1. Angle to or away from the swath. The -030 in the right display 156 means an intercept angle of 30 degrees toward the swath centerline is established. The minus will change to plus if, for example, an aircraft right of the swath centerline turns away from the swath. The illustration in Fig. 14B shows how the angle window will change relative to the aircraft’s approach toward or departure from the swath centerline.
2. 0020 the current swath number. The pilot selects this option in the Program Screen.

The upper row of lights 151,153 provides distance in feet to the swath centerline, rate of drift toward or away from centerline, and direction left or right to the centerline. Each light-pair, i.e., #1 left and right through #15 left and right is programmable in the Program Screen 130 to indicate a specified number of feet off track, e.g., 3 feet or 5 feet, depending on user preference.

Using the three foot example above, a single GREEN light 151 would mean, left of centerline by 3 feet, turn right. If the vertical row of yellow lights 155 are lit, it means on track, steady as you go. Three redlights 153 means 9 feet right, turn left to correct.

In a normal operating mode the AirStar system updates the lightbar five times per second. Rate of approach toward, or away from, the swath centerline can be judged by the rate at which the lights 151, 153 are being extinguished, or illuminated, respectively (the rate is a function of the intercept angle, ground speed, and displacement value assigned to each light).

The center column of yellow lights 155 represents swath centerline when a pattern has been initiated.

The lower row of lights displays the difference (angle, in degrees) between the
aircraft’s track over the ground and the track of the current swath. It is programmed in the Program Screen. For example, as seen in Fig. 14D, an aircraft tracking 330 degrees true and approaching from the right a swath with a true course of 360 degrees, represents an intercept angle of 30 degrees, which will be reduced to 0 degrees as the aircraft intercepts and parallels to align with the swath.

The technique for flying the lightbar 46 varies widely from pilot to pilot. Both rows of illuminated lights will always indicate the direction to turn to close the distance to the swath. When in doubt, turning into the lit upper lights always decreases the distance to the swath, while concurrently increasing the angle of intercept (shown by the lower lightbar).

Initially it may be beneficial to turn off the lower lightbar 152, 154 by entering 99 in the lightbar angle setting displayed in the Program Screen 130 (accessed by depressing the * button 71 on the keypad 60). Be sure to depress the ENTER button 77 prior to exiting the Program Screen with the SWATH button 64. This action will allow the pilot to concentrate on the upper light bar. Angle information can still be displayed (optional with Swath Number) in the right digital window 156.

The system allows entry of a single value, i.e., 4 or 5 or 6... etc., for each lower light 152, 154 each one of which will be scaled in degrees by the selected increment to provide an increasing incremented series i.e., 4, 8, 12, or 5, 10, 20, or 6, 12, 18 etc.

The system may also be programmed to allow for individually programmable lights, as in the upper row of lights 151, 153. Variable degree settings may be programmed into the lower lightbar to the tenth of a degree. This feature gives faster response to angle deviations when on-track during swathing. To select, enter Program Screen and scroll to ANGLE settings. Enter setting, in feet, and scroll to next entry.

Recommended settings.

<table>
<thead>
<tr>
<th>Light Number</th>
<th>Option 1</th>
<th>Option 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>* 30</td>
<td>15</td>
<td>89</td>
</tr>
<tr>
<td>14</td>
<td>82</td>
<td>83</td>
</tr>
<tr>
<td>13</td>
<td>75</td>
<td>76</td>
</tr>
<tr>
<td>12</td>
<td>68</td>
<td>70</td>
</tr>
<tr>
<td>11</td>
<td>61</td>
<td>64</td>
</tr>
<tr>
<td>10</td>
<td>54</td>
<td>58</td>
</tr>
</tbody>
</table>
The lightbar 46 example in Fig. 14D represents the picture illustrated above the lightbar:

The L030 in the left data window 157 means the swath centerline is 30 feet to the left.

The 030 in the right data window 156 means a left angle of intercept of 30 degrees closing toward the swath centerline.

The upper row of lights 153, 10 red lights illuminated @ 3 feet per light, indicates swath centerline is 30 feet to the left.

The lower row of lights 154, the #5 green light illuminated @ 6 degrees per light, indicates an angle of intercept of 30 degrees.

As the aircraft approaches the swath, the number of lit 5 upper lights 153 will decrease toward the center, and the pilot, based on the decrease in distance, and rate of decrease, will decrease the intercept angle, which will be also indicated by the lit lower light # also decreasing toward the centerline. Conversely, if the aircraft was at a greater distance from the swath, a greater intercept angle may be desired. The pilot would turn further left (indicated by the lit lower light # 154 moving further left as the intercept angle increases). Because of this turn to cross the swath and close the distance to the swath more rapidly (increase the correction), the lit number of upper lights will begin to decrease more rapidly and will require the pilot to use a steeper angle of bank turning
toward the swath true course (take out the correction) as centerline is approached. See Figs. 14E-14F.

The table in Fig. 15 relates the Angle-Of-Intercept to the Off-Track position. In order to accomplish a smooth intercept, the pilot will vary angle-of-bank so as to keep the lit lower light 152, 154 (angle) exactly beneath the outboard lit upper light 151, 153. If the intercept angle is too large, relative to the optimum value, then the lower light will be outboard of the upper lights, therefore the pilot would steepen the angle-of-bank turning toward the swath true course to reduce the intercept angle (bring the lower light closer to and beneath the outboard lit upper light). Conversely, if the intercept angle is too small, the lit lower light will be inboard of the outboard lit upper light and the pilot will need to shallow the angle-of-bank to allow the outboard lit upper light to decrease and drift in to a point above the lit lower light until they are vertically in line with each other. Then the pilot should reestablish the steeper bank turning toward the swath true course needed to keep the vertically aligned lit lights moving in toward the center column of amber light 4 together. (See Figs. 14E 14F).

To use the values in the table of Fig. 15 where the lightbar settings are 4 degrees per light:

1. Determine the type of pattern, i.e., Light & Tight, Normal, or Heavy Wide.
2. Select the Program Screen (press * button 71 on keypad 60).
3. Scroll to Lightbar Angle and enter 04 (4 degrees).
4. Scroll to the Light setting and enter the values (feet) from the table, starting with #1, for Light & Tight: 3-13-29-51, etc., thru light number 15.

The example shown in Fig. 14E is from the table in Fig.15 with values from the Light & Tight column: 40 degrees intercept angle and displacement of 309 feet. Should
the aircraft overshoot, the upper lights will shift to the right (red to green) and increase until the aircraft turns through a track parallel to the swath.

The system provides seven programmable options for either lightbar digital windows 156, 157 as follows:

SPD= groundspeed; ERR=feet off swath; TRK=track across ground; SW# = current swath number; ANG=track crossing angle in degrees; A/P=Acres/Pasa (cumulative); HDG=true heading (available only with flux-gate compass).

To select an option:

Press * key 71 to enter Program Screen.
Press ENTER key 77 to scroll to options menu.
Press UP or DOWN Arrow keys 68, 72 to scroll the 7 options.
Press ENTER key 77 to accept selected option.
Press SWATH key 64 to return to Swath Screen 100.

h. The Flow Controller

Fig. 16 shows a conventional flow controller system 160 currently widely used in applying a materials using an agricultural ("AG") airplane. Examples of these materials are pesticides, herbicides, seed, fertilizer and bait, all of which may be in liquid or dry form. To begin application of the chemical to a field or area, the pilot 169 must first turn on the pump 161. The pump may be either an electrical, hydraulic or wind-driven pump. With the shut off valve 162 in the off position, the chemical inside the tank 163 is pumped through the shut off valve 162 and the recirculation line 164 back to the tank. This action pressurizes the system in preparation for spraying. When the pilot is over the
point in which application is needed, he manually repositions the shut-off valve 162 to the on position by an amount based on past experience needed to meter the desired flow rate of the chemical. While flying the pass, the pilot monitors air speed 165 and flow readout 166 measured by the flow meter 167. When the flow readout 166 varies from the desired value, the pilot manually adjusts the control valve 162 to maintain the proper flow rate to the nozzles 168. The pilot must manually adjust for wind direction and speed. At the end of the last pass over the application area, the pilot manually turns the shut-off valve 162 to the OFF position.

When in position for the second pass over the application area, the pilot repeats the previous cycle. Obviously, this method of application control is inaccurate and heavily dependent on pilot interaction. Pilots cannot accurately compensate for variations caused by wind speed and direction. The pilot visually monitored system pressure and flow readout and manually adjusted based upon a predetermined estimated ground speed as best he could.

Fig. 17 shows the improved flow controller system 170 of the present invention which reduces pilot workload and maintains a high degree of accuracy and accountability of application of the material.

In the present invention 170 computer control essentially replaces the pilot interaction in the prior art system 160. As shown in Fig. 17, the flow controller module 171 automatically and continuously monitors actual ground speed and true position over the earth provided by the differential global positioning system. The precise position provided by DGPS allows for precise application of the chemical to the desired area. Variations in ground speed are quickly, accurately and automatically adjusted. The pilot's interaction is reduced to simply monitoring when to begin and stop spraying and
monitoring the actual flow rate desired, i.e., the gallons of chemical dispensed per acre, per linear distance, or per minute. The flow controller 171 does the rest of the work. Thus, the system monitors and delivers application material volume as a function of time as demanded in real time by the host system.

Shown in Fig. 17 is one embodiment of the invention, wherein a flow control module 171 is a stand alone enclosure housing a digital microprocessor or microcontroller which controls integral units which include shut off valve 175, flow control valve 180 and flow meter 181. System set up requires input or update of system component parameters infrequently changed, mission specific parameters, and material specific parameters, which affect flow, such as, flow rate in volume/time or volume/distance or volume/area, swath width, spray boom width, desired ground speed, starting payload and viscosity.

As the pilot approaches the area to be sprayed, the flow controller 172 automatically turns on the pump 173 to pressurize the system causing the chemical to be recirculated 174 through the shut-off valve 175 back to the tank 176 with flow control valve 180 off. At the "begin application" point, the pilot 177 presses the spray on switch (not shown). This command is received 178, 179 by the flow controller 172 which opens the flow control valve 180. Thereafter, the flow controller 172 continuously monitors the flow meter 181 and maintains the rate preselected by the pilot 177, 178, 179 by making automatic adjustments to the flow control valve 180 to compensate for any deviations which would alter the actual ground speed and track over the ground as reflected by the DGPS 182. Upon completion of the pass, the pilot 177 presses the spray off switch which command is received 178, 179 by the flow controller 172 which then shuts off valve 180. On the next pass the cycle is repeated.
Information such as actual flow rate, amount of chemical remaining in the tank 176, amount of chemical used, wind, speed or stuck valve may be displayed to the pilot for constant monitoring of the system.

The present invention uniformly applies a prescribed amount of agricultural product, liquid or solid, by unit area and measures the rate at which the product is dispensed in real time and logs and displays the results. For certain solid materials the flow control valve 180 and flow meter 181 are replaced with a positive displacement pump that is demanded by the controller to deliver a specific volume of material as a function of time. Real time tracking of the remaining pay load and the total material applied is also provided. The system automates the initiation of chemical application based on the location of the application vehicle and a preprogrammed spray area.

The flow controller 172 of the present invention may be used, as shown above, with a host system such as the DGPS 182, that provides accurate ground position/speed information. The host system 182 provides a user interface 179 to the flow controller 172. Alternatively, the flow controller 172 may be incorporated as an actual part of the host system 182 as a single component.

One example of a host system 182 is the AirStar DGPS Swath Guidance System with dual row lightbar described in the present application and manufactured by SATLOC, Inc. of Casa Grande, Arizona. This host system, when connected to control the flow controller system 170 described above, is described as providing "Spray Sentry" 170 capability. The host system may provide the equipment operator functionality that is equal to or considerably beyond that required to support the flow controller 172 alone. Alternatively, a simplified system would integrate the position, speed sensing and demand
generation functions into the flow control module.

The embodiment disclosed in Fig. 17 is the present preferred mode. Other system configurations are possible. For example, the system may comprise separate flow control module, flow monitor module, and proportioning module to carry out these separate functions. Alternatively, the flow controller 172 shown in Fig. 17 may be separate from the shut off valve, flow control valve and flow meter, the latter three being each separate units.

Alternatively, the sequence of events for dispensing may be controlled in another way. With a constantly driven pump 173, the pilot approaches the area to be sprayed with shut off valve 175 off. Based on GPS supplied ground speed 182 flow controller 172 prepositions flow control valve 180 to a "best guess" opening. As the pilot 177 reaches the point of begin application, he manually opens shut off valve 175, as shown by the dotted line 177a in Fig. 17, causing material to flow through flow control valve 180 and flow meter 181 to the nozzles 168. The pilot's opening of the shut off valve 175 is sensed by the flow controller 172 via a limit switch (not shown). As previously explained, thereafter the flow controller 172 continuously monitors flow meter 181 and maintains the rate preselected by the pilot 177, 178, 179 by making automatic adjustments to the flow control valve 180 to compensate for any deviations which would alter the actual ground speed and track over the ground as reflected by the DGPS 182.

Upon completion of the pass, the pilot 177 manually closes the shut off valve 175 which is sensed by the flow controller via a limit switch (not shown) and the flow controller 172 reverts back to prepositioning the flow control valve 180 in preparation for the next pass.

Alternatively, in another embodiment the functionality of the shut off valve 175
and the flow control valve 180 may be integrated into a single valve (not shown) wherein
the on-off and metering functions are manually or electronically controlled or both or
some combination thereof.

As a further enhancement to all of the embodiments described above, the addition
of a pressure sensor 175a monitored by the flow controller 172 can greatly augment the
status and dynamic response of the control loop by largely reducing gain modulation of
the control loop due to shut off valve position and pump pressure variations.

The Spray Sentry 170 settings are displayed by the VIEW Button 62 on keypad
60. Press SWATH key 64 to exit. These keys are not functional unless the Spray Sentry
170 feature is installed in the AirStar system. To select Acres Per Pass, press 5 VIEW
key 62, scroll to Acres/Pass Y/N, and toggle "Y". Cumulative acres will be tabulated,
based on swath width and ground speed, when the PLOT button 66 ia pressed or spray
is actuated. To display the result in the left or right digital window on the lightbar 46,
select A/P as the programmable lightbar 46 option described earlier.

Examples of applications of the Spray Sentry 170 feature range from crop dusting
to spraying oil dispersant over oil-laden waters. The efficiency of Spray Sentry 170
optimizing spray application and minimizing excess application results in a typical
savings of 35% of chemical cost alone.

4. QUICK-START CHECKLIST AND GENERAL OPERATION OF THE SYSTEM

A quick-start checklist for start-up of the system combined with a general
description of the operation of the system as generally set forth in the flow chart 200
shown in Figs. 18A and 18B follows:

First, insert Memory Card 43 into the slot provided in the front face of computer
and GPS receiver unit 41.

Second, turn 201 the Power switch 51 ON. The LEFT GREEN LIGHT 47 on display 45 will go ON.

Next, the computer 41 loads 202 its software and performs a built-in test sequence which is an automatic series of internal systems tests which results first in the illumination of the SYS 91 and DIFF 93 lights on the DISPLAY box 45 and all of the lights/digital windows on the Lightbar 46. Shortly thereafter the SYS 91 and AREA 94 lights illuminate followed by "Display 90 Self Test" which is followed by "LED SelfTest" which gives the following indication: "In Progress, Version 1.0." Thereafter the AREA light 94 goes out and the GPS 92 and DIFF 93 lights illuminate momentarily, but then only SYS 91 light remains illuminated until completion of all remaining tests. The next test is "Lightbar SelfTest In Progress", followed by "Optional Features LG = N WD = N CH = N WP = N F4 = N FS = N F6 = N F7 = N" followed by "GPS Initialization In Progress", followed by "GPS Configuration In Progress", followed by "Swath Screen - WAIT GPS". At this point the computer is determining 203 whether it has a GPS fix. If not, it continues to wait 204 and retries. When the GPS fix is obtained, the computer moves to the next program step of determining 205 what swath pattern will be used. The swath pattern is set by selecting Direction-RIGHT OR LEFT, Pattern 206 BACK-TO-BACK, RACETRACK, or SQUEEZE, wherein the display 90 changes 209 to "WAITING-A".

The pilot selects the Programming Screen to CHECK set-up by scrolling the entire menu to be sure all settings are correct. In the process the pilot sets Swath Width, 207 (default 208 is 75 feet), Log Interval, Log Speed MPH, Mask Angle 5, and the Lightbar.

To complete the quick-start checklist, the pilot selects the GPS Satellite Screen
120 to Check BT=OK, DF=>00, i.e., 02., Number of Satellites, DOP (<4.0 is best). At this point display box 45 left green lite 91 is ON, all red lights 92, 93 are OFF, the SAVE/PURGE key 74 is depressed to CHECK MINUTES REMAINING on memory card 43 and, finally, the system is Ready to Spray.

Once airborne, the pilot can perform a confidence check on the system. The pilot sets up the A-B line on a known straight line such as the centerline of the runway. He then flies several swath advances, and then, decreases the swath back to #1. He lines up on the runway centerline and notes that the lightbar centers up, right down the swath centerline. He flies this numerous times until he gets the feel for making smooth corrections, and, just as importantly, has the confidence that the system flies straight.

Having completed the confidence check and with display 45 showing "Waiting A" on swath screen 100, the computer is determining 209 whether a grid has been laid out. To complete the grid the pilot flies 210 the A-B/C lines to set up the grid. Once the grid is laid out, the program steps to determine 211 the latest position from the GPS receiver and compares 212 the current aircraft position with the desired position as predicted by the grid.

The computer next determines the lateral position of the aircraft relative to the selected swath track the pilot desires to fly. The results of this evaluation will control the driving of the upper bar lights 151, 153 and the left hand digital display 157 in lightbar 46. Having determined 214 how far left or right the aircraft is, the result is converted 215 to lighting a prescribed number of LED’S using the variables as set by the pilot in the menu. If the aircraft is left of desired track by an amount greater than X, the system drives 216 the prescribed number of green lights 151 on the upper lightbar. It also drives 220 the left hand digital display 157 showing the off track error in feet. If the aircraft is
off track by an amount greater than X to the right of the desired track, the system drives 217 the prescribed number of red LED's 153 in the upper lightbar and drives 220 the left hand digital display 157 to show the off track error in feet. If the off track error is less 218 than X, the system drives 219 the amber light 155 at the center of the upper light bar and drives 220 the left hand digital display 157 showing the off track error in feet.

Next, the system determines the intercept angle being flown by the aircraft relative to the true course of the selected swath line 221. If the track angle is less 222 than the amount V obtained 223 from the pilot's keypad input, or defaulting 224 to a setting of 5 degrees per light, the system drives 225 the amber light 155 in the center of the lower lightbar. If the track angle is more than the value set by the pilot, the system divides 226 the amount of the track angle by the variable V to obtain a quotient.

Next, the system determines 227 whether the current track will reduce the off track position error. If it does, the system will illuminate 229 the appropriate # LED on the lower lightbar equal to the quotient distance from the center LED on the side of the lightbar opposite the side of the swath line on which the aircraft is actually located. If the current track will not reduce the off track position error, the system will light 228 the appropriate # LED on the lower lightbar equal to the quotient distance from the center LED on the side of the lightbar the same as the side of the swath line on which the aircraft is located. Finally, having completed lateral distance and intercept angle calculations and illuminations, the system returns 230 to obtain 211 the latest position from the GPS receiver, and repeats the cycle all over again.

In using the present invention, it is important to fly the aircraft; It is important not to fixate on the Lightbar 46. The pilot should fly the best turn for the conditions, then check the Lightbar 46 to tell how well he did. This technique results in better turns and
smaller corrections to be on the centerline of the swath. With practice the Lightbar 46 indications and corresponding corrections become second nature. Experimentation with the settings to find the best combination is encouraged.

The foregoing description of a preferred embodiment and best mode of the invention known to applicant at the time of filing the application has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously many modifications and variations are possible in the light of the above teaching. The various embodiments were chosen and described in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.
1. In a rover guidance system for determining position from satellite signals including receiving signals from a plurality of satellites in a constellation known as the global positioning system to determine a position of the rover over the earth, and receiving data from a base radio to correct the position, and means for computing a corrected position of the rover from the correction data wherein the improvement comprises: means for using the corrected position to guide the rover in an agricultural swathing operation.

2. In a rover guidance system as set forth in claim 1 wherein: the means is a continuous display of the corrected position enabling an operator of the receiver to guide the rover.

3. In a rover guidance system as set forth in claim 2 further comprising: a first receiver means receiving range measurements from the GPS antenna, and a second receiver means receiving corrected range data as the correction data from which a true rover position is computed.

4. In a rover guidance system as set forth in claim 2 further comprising: a display of the corrected position relative to a preselected swath line of a preselected swath pattern.
5. In a rover guidance system as set forth in claim 4 further comprising:
   the swath pattern being selected from the group consisting of back-to-back,
   racetrack or squeeze.

6. In a rover guidance system as set forth in claim 4 further comprising:
   means for advancing the guidance from swath to swath.

7. In a rover guidance system as set forth in claim 2 further comprising:
   means for defining swath width and a right or left swath pattern layout.

8. In a rover guidance system as set forth in claim 7 further comprising:
   means for defining an A-B reference line for the swath pattern and
   computing a field layout in successive, parallel, equally spaced tracks in the direction
   preselected by the operator.

9. In a rover guidance system as set forth in claim 8 further comprising:
   means for displaying deviations from a swath centerline by lighting light
   R in a lightbar.

10. In a rover guidance system as set forth in claim 9 wherein:
    the lights in the lightbar are preprogrammable so that when the lights are
    illuminated, the deviations are indicated in units equivalent to rover lateral displacement
    from the centerline in direction and amount and angle of intercept with the centerline in
    direction and amount.

11. In a rover guidance system as set forth in claim 9 further comprising:
    means for digitally displaying adjacent the lightbar a rover lateral
    displacement from the centerline in direction and amount and angle of intercept with the
    centerline in direction and amount.

12. In a rover guidance system as set forth in claim 8 further comprising:
means for defining a width of a field and computing field layout therefrom.

13. In a rover guidance system as set forth in claim 7 wherein:
the defining means is an operator keypad for inputting predetermined
parameters.

14. In a rover guidance system as set forth in claim 2 further comprising:
means for recording the positions traversed during the operation and for
reproducing the recorded data as a map of the field swathed.

15. In a rover guidance system as set forth in claim 2 further comprising:
a dual row lightbar for displaying rover lateral displacement from swath
line in one row and intercept angle with the swath line in the other row.

16. In a rover guidance system as set forth in claim 15 further comprising:
means for continuously indicating rover’s rate of closure with the swath
line and the swath true course.

17. In a rover guidance system as set forth in claim 16 wherein:
the rate of closure is indicated by the rate at which the lit lights in the
lightbar decrease toward the center of the lightbar.

18. In a rover guidance system as set forth in claim 16 further comprising:
means for indicating the rates of closure relative to each other.

19. In a rover guidance system as set forth in claim 18 wherein:
the relative rates of closure are indicated by the vertical alignment of the
outboard lit light in each row as the lit lights decrease toward the center of the lightbar.

20. In a rover guidance system as set forth in claim 15 wherein:
the lateral displacement in direction and amount is displayed in the upper
lightbar and left digital display, and
the intercept angle in direction and amount is displayed in the lower lightbar and right digital display.

21. In a rover guidance system as set forth in claim 15 wherein:

the lateral displacement is displayed by lighting an equivalent number of lights in the upper row, and

the intercept angle is displayed by lighting an equivalent one of the lights in the lower row.

22. In a rover guidance system as set forth in claim 15 further comprising:

the lightbar having

a housing the inner roof of which is dark, and

a front transparent window covered by a circular polarizing material affixed thereto supported in the housing at an upward angle relative to a horizontal plane substantially perpendicular to a front face of the lightbar such that the first reflection is of the dark inner roof

whereby the readability of the lightbar is substantially enhanced even in direct sunlight.

23. In a rover guidance system as set forth in claim 2 further comprising:

a flow controller for varying the amount of dispensed agricultural product over the ground as a function of rover ground speed determined by the global positioning system to dispense a predetermined amount of the product.

24. In a rover guidance system as set forth in claim 23 wherein the flow controller further comprising:

means for delivering the product as a function of rover actual position over the ground determined by the global positioning system.
25. In a rover guidance system as set forth in claim 24 further comprising:
computing means for automatically
beginning and stopping flow upon receiving respective begin and
stop signals from the operator.

26. In a rover guidance system as set forth in claim 24 further comprising:
computing means for continuously
monitoring the ground speed, position over the ground and the flow
rate of dispensing the product, and
automatically adjusting flow rate to dispense the predetermined
amount of the product.

27. In a rover guidance system as set forth in claim 26 further comprising:
means for logging data describing the flight path and the location and
amount of agricultural product dispensed.

28. In a rover guidance system as set forth in claim 2 further comprising:
a flow controller for varying delivered agricultural product over the ground
as a function of rover actual position over the ground determined by the global
positioning system to dispense a predetermined amount of the product.

29. A dual row lightbar for guiding a rover relative to a centerline comprising:
a display of rover lateral displacement from the centerline in one row, and
a display of rover intercept angle with the centerline in the other row.

30. A dual row lightbar as set forth in claim 29 further comprising:
means for continuously indicating rover's rate of closure with the centerline
and the true course of the centerline.

31. A dual row lightbar as set forth in claim 30 wherein:
the rate of closure is indicated by the rate at which the lit lights in the lightbar decrease toward the center of the lightbar.

32. A dual row lightbar as set forth in claim 30 further comprising:
means for indicating the rates of closure relative to each other.

33. A dual row lightbar as set forth in claim 32 wherein:
the relative rates of closure are indicated by the vertical alignment of the outboard lit light in each row as the lit lights decrease toward the center of the lightbar.

34. A dual row lightbar as set forth in claim 29 wherein:
the lights in the lightbar are preprogrammable so that when the lights are illuminated, rover deviations from the centerline are indicated in units equivalent to rover lateral displacement from the centerline in direction and amount and angle of intercept with the centerline in direction and amount.

35. A dual row lightbar as set forth in claim 29 further comprising:
means for digitally displaying adjacent the lightbar rover lateral displacement from the centerline in direction and amount and rover angle of intercept with the centerline in direction and amount.

36. A dual row lightbar as set forth in claim 35 wherein:
the lateral displacement in direction and amount is displayed in the upper lightbar and left digital display, and
the intercept angle in direction and amount is displayed in the lower lightbar and right digital display.

37. A dual row lightbar as set forth in claim 29 wherein:
the lateral displacement is displayed by lighting an equivalent number of lights in the upper row, and
the intercept angle is displayed by lighting an equivalent one of the lights in the lower row.

38. A dual row lightbar as set forth in claim 29 wherein:
the lights in both rows left of center are red,
the lights in both rows right of center are green, and
the center lights in each row are yellow.

39. A dual row lightbar as set forth in claim 29 wherein:
the centerline is a swath line of a swath pattern for dispensing an agricultural product, and
the lateral displacement and angle of intercept are continuously provided by a differential correction global positioning system.

40. In a dual row lightbar as set forth in claim 29 comprising:
the lightbar having
a housing the inner roof of which is dark, and
a front transparent window covered by a circular polarized material affixed thereto supported in the housing at an upward angle relative to a horizontal plane substantially perpendicular to a front face of the lightbar such that the first reflection is of the dark inner roof
whereby the readability of the lightbar is substantially enhanced even in direct sunlight.

41. A lightbar comprising:
a housing for supporting lightable data symbols, and
a front transparent window covered by a circular polarized material affixed thereto supported in the housing at an upward angle relative to a horizontal plane
substantially perpendicular to a front face of the lightbar such that the first reflection is of the dark inner roof.

whereby the readability of the lightbar is substantially enhanced even in direct sunlight.

42. A rover dispensing system comprising:

a global positioning system receiver for continuously determining the ground speed and position of the rover over the earth, and

a flow controller for varying the amount of dispensed product as a function of rover ground speed and rover actual position over the earth determined by the global positioning system receiver to dispense a predetermined amount of the product.

43. A rover dispensing system as set forth in claim 42 wherein:

the receiver is a differential correction global positioning system receiver.

44. A rover dispensing system as set forth in claim 43 further comprising:

computing means for automatically beginning and stopping flow upon receiving respective begin and stop signals from the operator.

45. A rover dispensing system as set forth in claim 43 further comprising:

computing means for continuously monitoring the ground speed, position over the ground and the flow rate of dispensing the product, and

automatically adjusting flow rate to dispense a predetermined amount of the product.

46. A rover dispensing system as set forth in claim 45 further comprising:

means for logging data describing the flight path traversed and the location
and amount of product dispensed.

47. A rover dispensing system as set forth in claim 43 further comprising:

the flow controller prepositioning a flow control valve in the flow line to

a best guess position while the flow in the line is off.

48. A rover dispensing system as set forth in claim 47 further comprising:

the flow controller controlling the flow control valve in an automatic flow

adjusting mode in response to a signal from the operator and when there is flow in the

line.

49. A rover dispensing system as set forth in claim 43 further comprising:

the flow controller being responsive to a pressure sensing means positioned

in the flow line for enhancing dynamic and static response of the flow controller.

50. A rover dispensing system as set forth in claim 49 wherein:

the pressure sensing means is positioned ahead of a flow control valve in

the flow line.
FIG. 7

FIG. 8

FIG. 9
FIG. 10

FIG. 11
FIG. 13A

FIG. 13B

FIG. 13C

FIG. 13D

FIG. 13E

FIG. 13F
<table>
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<tr>
<td>Light &amp; Tilt</td>
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<tr>
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<td>Upper Lightbar</td>
</tr>
<tr>
<td>Lower Lightbar</td>
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<tr>
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<tr>
<td>Heavy &amp; Wide</td>
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<tr>
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<tr>
<td>Degrees</td>
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<tr>
<td>Feet</td>
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</table>

**Example Table Data**

- Light Number 1: 6000 feet, 90 degrees
- Light Number 2: 7000 feet, 100 degrees
- Light Number 3: 8000 feet, 110 degrees

**FIG. 15**

**SUBSTITUTE SHEET (RULE 26)**
FIG. 18A

POWER ON 201

COMPUTER SOFTWARE LOADED 202

RETRY 204

DO I HAVE GPS FIX? 203

WHAT SWATH PATTERN? NO 205

WAIT FOR GPS FIX

SELECTION 207

WHAT SWATH SPACING? 75' (OR AS PER PILOT INPUT) 208

STORE & RETURN

PILOT'S MENU (SET BY KEYPAD)
1. BACK-TO-BACK
2. RACETRACK
3. SQUEEZE

PILOT FLY'S A-B/C TO SET UP GRID NO 209

GET LATEST POSITION FROM GPS RECEIVER * ENTER

COMPARE CURRENT POSITION WITH DESIRED POSITION AS PREDICATED BY GRID 210

AM I:
• LEFT OF TRACK?
• RIGHT OF TRACK?
• ON TRACK?

LEFT 214

HOW FAR?
RESULT=OFF TRACK 215

CONVERT OFF TRACK TO # OF LED'S USING VARIABLES AS SET BY PILOT IN MENU

CONVERT OFF TRACK TO # OF LED'S USING VARIABLES AS SET BY PILOT IN MENU

DRIVE GREEN LED'S ON UPPER LIGHTBAR

OFF TRACK < X

DRIVE RED LED'S ON UPPER LIGHTBAR

DRIVE AMBER LED'S AT CENTER OF UPPER LIGHTBAR
12/12

DRIVE L.H. DIGITAL DISPLAY SHOWING OFF TRACK IN FEET

GET CURRENT TRACK IN DEGREES FROM GPS RECEIVER. COMPARE WITH DESIRED TRACK SET BY A-B LINE

DRIVE AMBER LED ON LOWER LIGHTBAR

IS TRACK ANGLE < V? PASS < TO PROCESS BELOW

GET VARIABLE FROM PILOT'S INPUT KEYPAD MENU

PILOT'S MENU V=5 (OR AS PER PILOT INPUT)

DIVIDE TRACK ANGLE BY V TO GET QUOTIENT

SAME

DRIVE LED ON LOWER LIGHTBAR EQUAL TO QUOTIENT DISTANCE FROM CENTER OF LED

OPPOSITE

DRIVE LED ON LOWER LIGHTBAR EQUAL TO QUOTIENT DISTANCE FROM CENTER OF LED

WILL CURRENT TRACK REDUCE OFF TRACK POSITION ERROR?

RETURN TO * ENTER

FIG. 18B
A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) : G01S 5/02; G01C 21/00, 23/00; G06F 7/70
US CL : 342/357; 340/979, 973; 364/424.06, 424.07
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
U.S. : 342/357; 340/979, 973, 980, 971; 364/424.06, 424.07, 424.01, 424.02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
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<td>and 29-50</td>
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<td>X, P</td>
<td>US, A, 5,369,589 (STEINER) 29 November 1994, entire document.</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

Date of the actual completion of the international search: 27 MARCH 1995

Date of mailing of the international search report: 17 APR 1995

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Telephone No. (703) 308-0511

Form PCT/ISA/210 (second sheet) (July 1992)
### INTERNATIONAL SEARCH REPORT

**DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
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<tr>
<td>A</td>
<td>US, A, 4,299,483 (GROVE ET AL.) 10 November 1981, Figure 4.</td>
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<tr>
<td>A, P</td>
<td>US, A, 5,359,326 (BIVENS ET AL.) 25 October 1994, Figure 3.</td>
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