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CANAAN AVIONICS

MULTI-LINK DROP COMPUTER FOR AERIAL FIRE FIGHTING

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SYSTEM OBJECTIVE:

Currently, aerial firefighting is conducted via Visual Flight Rules (VFR) and relies heavily on aural communication to coordinate aerial assets. The number of aircraft involved in a single aerial firefighting mission has increased dramatically, chiefly due to the effectiveness of the technique and the eagerness of agencies to utilize it. Inevitably, traffic control and drop coordination has become an increasing challenge for fire fighters due to a limited means of communication, coordination and navigation. Communication and coordination task can over burden aircrews, taking attention away from maintaining their aircraft's flight envelope and separation from terrain. There is a demand for a tailor made avionics system which would consolidate all of the aforementioned tasks in order reduce pilot workload, increase pilot situational awareness, and efficiently communicate mission objectives.

Canaan Avionics is proposing a dedicated aircraft computer called a Multi-Link Drop Computer (MLDC). The MLDC concept provides accurate navigation data to drop points for aerial firefighting aircraft. The MLDC allows flight crews and mission coordinators to quickly and accurately communicate drop point coordinates which will maximize coordination efficiency. Drop coordinates will be displayed using basic flight instruments, paving the path for Instrument Flight Rules (IFR) firefighting operations.

The MLDC utilizes a low speed modem, interfaced with a communication radio [voice and/or satellite] to quickly transfer drop coordinates and other mission related data. Drop coordinates are 'squawked' to aerial assets through any communication channel using a complementary MLDC unit by mission coordinators on the ground or in the air. Possible communication channels may be analog or digital voice radios and even TCP/IP communication through SATCOM and Automated Flight Following (AFF) systems.

The MLDC concept provides Long Range NAV (LRN) signals to the flight director systems to facilitate enroute IFR navigation to drop points. The MLDC outputs moving map data for display on electronic HSI's and EFIS systems. Simple LRN flight plans can be created, stored, and shared between aerial assets equipped with an MLDC. Ground controllers will be able to create flight procedures for aerial assets in the Fire Traffic Area (FTA) in real-time as conditions change.

When interfaced with dual WAAS GPS and a laser altimeter, the MLDC may also generate Short Range NAV (SRN) lateral and vertical guidance to facilitate an IFR drop approach. An IFR drop allows aircrews to fly a typical ILS-like approach to the drop point. Having IFR flight guidance dramatically lightens crew workload and provides guidance in low visibility conditions, as in smoke or at night.

The SRN mode [described above] is complimented with a progressive terrain avoidance advisory function called '*Go-Around Advisory*'. This function provides non-nuisance visual and aural annunciation of impending terrain for the purpose of minimizing Controlled Flight Into Terrain (CFIT) incidents.

The MLDC is a scalable design which is intended for Multi-Engine Tankers, Helicopters, Single Engine Airtankers (SEATS), and Very Large Airtankers (VLAT). The system interfaces with the existing avionics systems via non-proprietary, industry standard protocols.

DESIGN CONSIDERATIONS:

Compatibility: The MLDC interfaces with existing avionics systems via industry standard protocols. The MDLC outputs ARINC 407, 150mV Analogs Deviations, ARINC 429 and GAMA signals in the exact same way that commercial Flight Management Systems do. This ensures that the MLDC will interface with the existing avionics systems on all rotary, fixed-wing, military and civilian aircraft. Navigational information is displayed on existing avionics instruments and multi-function displays.

Scalability: The MLDC must interface with simple, antiquated avionics systems and modern digital avionics systems. The MDLC adds functions depending on existing sensor accoutrements on the aircraft. For example, if the aircraft has a WAAS compatible GPS system, the MLDC can provide IFR approach guidance. If the aircraft just has a VOR, the MLDC can provide drop guidance via a simple bearing pointer and DME readout.

Intuitiveness: The MLDC defines IFR enroute and approach procedures which pilots already know how to fly. Pilots will be able to fly drop procedures on the first day, without extensive training and familiarization. The user interface for the MLDC is intuitive, mimicking the flight planning functions of commercially available Flight Management Systems.

Convention: The MLDC integrates proved, existing technologies. The MLDC is more of an integration project; less a research project. Performance requirements for the MLDC are already defined by RTCA in *Minimum Operational Performance Standards (MOPS) for Global Positioning System/Wide Area Augmentation System Airborne Equipment, DO-229C.* With some specific exemptions and additions due to the uniqueness firefighting missions, the MLDC will comply with these MOPS.

Practicality: Commercially available systems, such as Terrain Awareness (TAWS/EGPWS) and Collision Avoidance System (TCAS), fail to be effective within the FTA because they were designed for standard flight operations, not drop operations over unimproved, undulating terrain. The MLDC allows Ground Coordinators and Lead Planes to create instant flight plans for individual aerial assets to ensure aircraft separation. The MLDC does not provide nuisance terrain alerts that the commercially available TAWS systems do. It gives crews the latitude to complete their mission under the unique conditions of drop operations by warning crews of separation issues before they occur, not while they occur.

Cost Effectiveness: The MLDC is just one box, not a complete avionics system or ground infrastructure. Because existing avionics systems are used and because the communication and coordination functions are adhoc, the scope of the MLDC solution is not broad. The MLDC relies on existing, proven technologies entirely. This reduces technical liability, research and Non-Recursive Engineering (NRE) costs.

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Distinction:
The MLDC is an alternative solution for VFR drop operations. Ground Controller and Lead Planes will be able to coordinate with aircraft that aren't even in the FTA yet. IFR guidance to drop zones will enable firefighting operations to continue around the clock. Digital asset coordination on the ground will supplement the existing AFF system giving Controllers a better picture of FTA operations in real-time.

The MLDC proposes a new type of terrain avoidance. Existing TAWS systems do not lend themselves over to firefighting operations. Terrain Collision Avoidance systems that are in developement, such as Auto-GCAS, require Trajectory Intent and autopilot integration. Most aircraft used in firefighting do not have systems compatible with Auto-GCAS. Others, such as C130's, would require extensive autopilot recertification (or even replacement) in order for 'Auto' part of Auto-CAS to be functional.

Auto GCAS also requires an accurate Digital Terrain Elevation Data map. This terrain database is already in use in commercially available TAWS systems. The problem is that the database does not accurately account for unimproved terrain. A new database must be created and maintained which accounts for wooded terrain so that the aircraft can maintain a measured degree of separation above the trees, not just the terrain under the trees.

It may not be possible for a terrain database which accounts for trees and other obstacles to have '*Critical'* integrity levels dictated by *AC25.1309-1A, System Design and Analysis*. Because of these technological and certification limitations, existing TAWS systems only allow aircraft to descend towards surveyed, approved runways, not towards wooded terrain.

For more information about Auto-GCAS, reference *NASA Dryden Flight Research Center, Auto-GCAS*.

The MLDC works with existing avionics systems and procedures to prevent CFIT. The MLDC utilizes laser altimetry to obtain an accurate, up-to-date ground profile of the drop approach. The MLDC issues conventional terrain cautions and warnings in the form of GA Advisories enabling the crew to level wings and climb on their own.

DIGITAL DATA LINK:

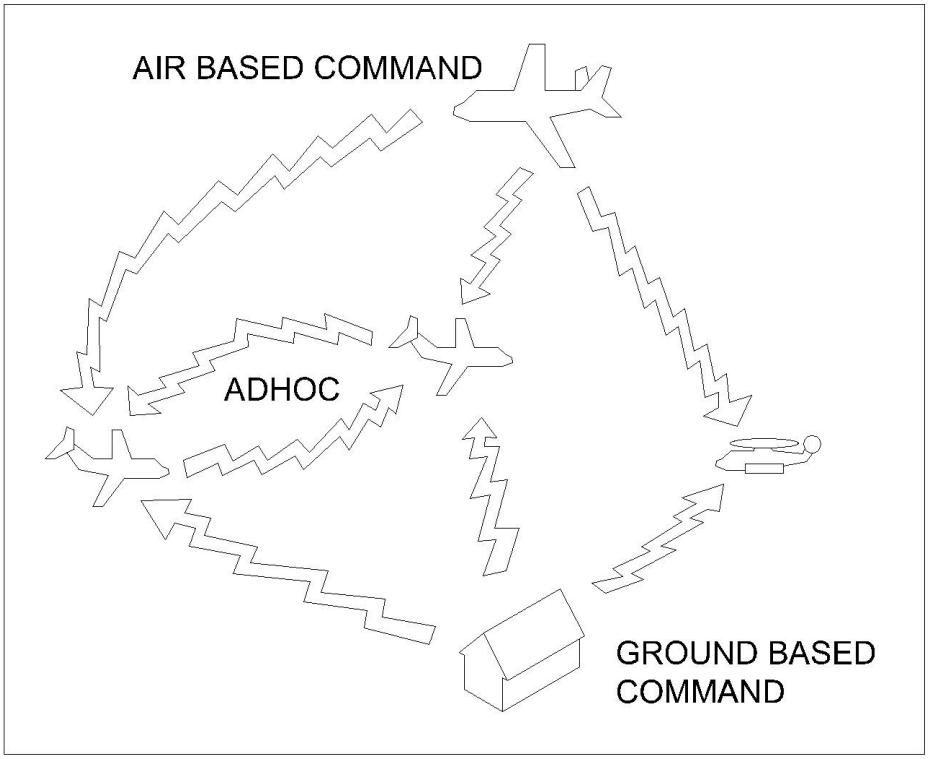

Figure 1, Multi-Source Data Communication

Each MLDC has an audio data link which will work with most any communication system. The audio data link is a low baud modem which allows drop point data to be sent wirelessly between any mission coordinator and aircraft crew, or even adhoc between two aircraft. Each MLDC allows the operator to store the drop point data into a series of PVOR presets, much like presets on a car radio. The data link is considered "multi" because it will work with most any VHF, tactical radio, or satellite telephone.

The US forestry Service has elected to use Automated Flight Following (AFF) systems on most assets. If need be, the MLDC can be interfaced via TCP/IP through the Iridium AFF network. This has the advantage of freeing up voice communication channels and doesn't have range limitations associated with voice communication radios. This will provide an elegant mission coordination solution that facilitates digital drop coordination and verification between aircraft operating in theater and/or a mission control located anywhere in the world.

LONG RANGE NAVIGATION SYSTEM OVERVIEW:

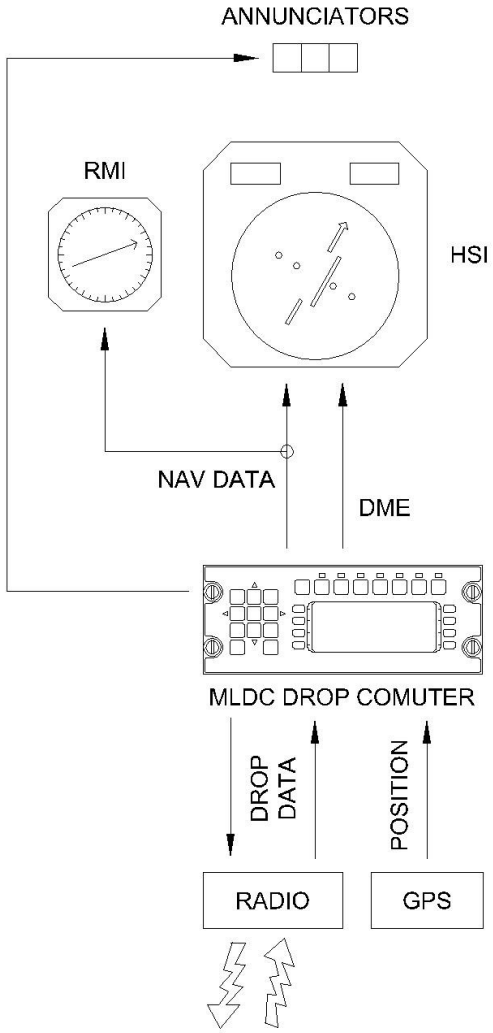

Figure 2, System Block Diagram of Typical Installation

The MLDC concept is designed to be a scalable navigation computer that works with existing certified avionics systems. Since the MLDC is scalable, it is able to integrate with large and small aircraft at an affordable cost.

Simple installations will enable the MLDC to interface with bearing and distance indicators to tell the pilot where to fly and how far to go. The MLDC can also interface with flight directors to provide enroute roll commands directly to the drop point. Other installations may be with highly integrated Electronic Flight Information Systems (EFIS). A single MLDC can be installed in small aircraft and dual installation can be performed in large aircraft for redundancy.

LONG RANGE NAVIGATION VIA BEARING POINTERS:

The most basic MLDC installation includes just a MLDC computer, GPS unit, Radio Magnetic Indicator (RMI) and communication radio. All aircraft already have a communication radio and RMI, and most have an onboard GPS unit. The MLDC will interface with these for easy installation in the smallest of firefighting aircraft. This enables small operators a means to receive drop coordinates through a communication channel and navigate to drop points using the bearing pointer and distance readouts.

The MLDC generates a Pseudo VOR (PVOR) station that has the same characteristics as a typical ground-based VOR. The PVOR represents the bearing and distance to a drop point. Drop points are stored in the MLDC as a latitude and longitude. The MLDC receives ARINC 429 data from an onboard GPS and uses basic trigonometry to compute PVOR bearing and pseudo distance (PDME) to the drop coordinates.

The MLDC outputs ARINC 429 and/or analog bearing and distance for use by onboard navigation instruments. The flight crew will have the ability to fly the PVOR radials to and from the drop point. The RMI will provide a bearing, the CDI will provide course deviation, and the flight director (if already installed on the aircraft) will provide roll guidance.

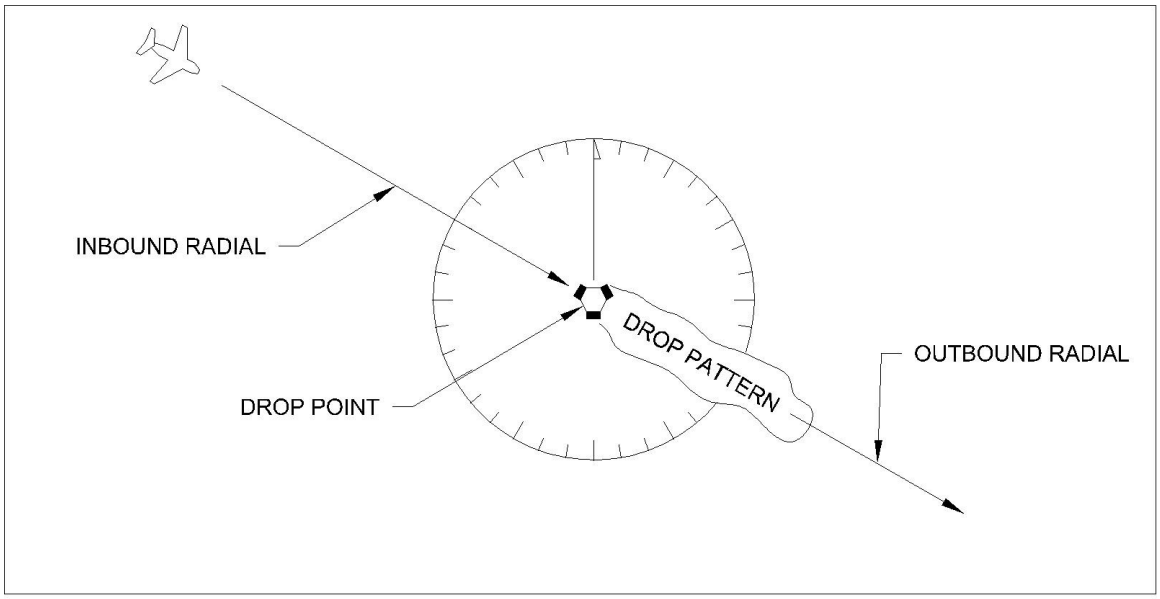

Figure 3, PVOR Navigation

Multiple drop coordinates and drop vectors can be used in succession for line building or concentrating coverage between drops. Figure 5 illustrates how drop coordinates can be positioned so that successive drops are where the pervious drop ends. In **Figure** 4, four different aircraft build a line with four different drop points. Drop coordinates can also be "side stepped" which would widen the coverage area.

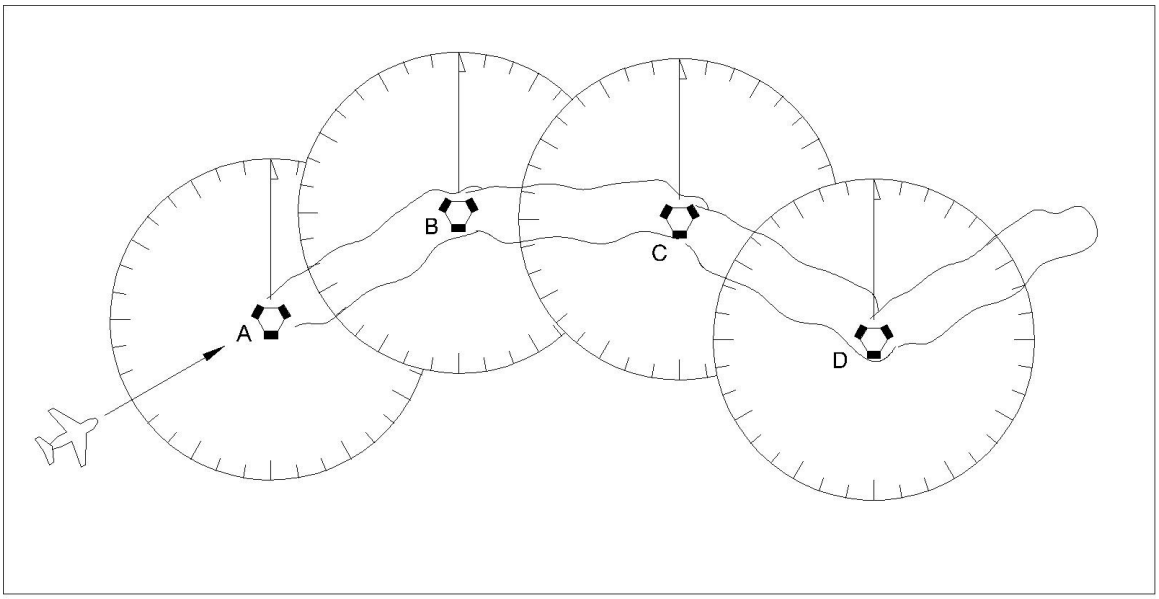

Figure 4, Line Building

Mission Example for LRN via Bearing Pointers: A Lead Plane marks drop points by flying over them and pushing a 'mark' button on the MLDC. This locks in the longitude and latitude of the drop point. The MLDC randomly assigns identification to the individual coordinates (for example ZEBRA18). The individual drop point identifications are never reused ensuring that all points are uniquely identified. The Lead Plane can mark many points, all with unique identifications, or stick with one drop point. In this example, the lead pilot flies along a line and marks four drop points in order to build a fire retardant barrier.

The Lead Plane pilot contacts aerial assets who are enroute on the radio. Using the MLDC, the lead pilot selects the inbound aircraft tail numbers from a list on the MLDC screen and 'squawks' the drop coordinates to them through the communication radio channel. A short series of tones (for about 1 second) transfer the navigation data to all inbound aircraft. The inbound aircraft whose tail number matches those selected by the Lead Plane receive the drop coordinates through their MLDC and the coordinates are loaded into their individual presets.

Four inbound aircraft verify the drop coordinates using the unique drop point identification displayed on the MLDC. Each of the firefighting aircraft select one drop point on the MLDC and the unit calculates the drop point bearing and distance. The MLDC drives the RMI and/or HSI pointers towards the drop point and the DME readout indicates the 'distance-to-go'. The pilots follow the bearing pointer and drop the retardant when their drop point is reached. A 'DROP' annunciator in the cockpit signals to the pilot when the drop point is reached. The four drop patterns from each of the aircraft overlap and build a line exactly where the Lead Plane marked it off.

Another option is for multiple aircraft to use the same drop point in order to deliver the agent from all aircraft onto a single point.

LONG RANGE NAVIGATION VIA ELECTRONIC DISPLAY:

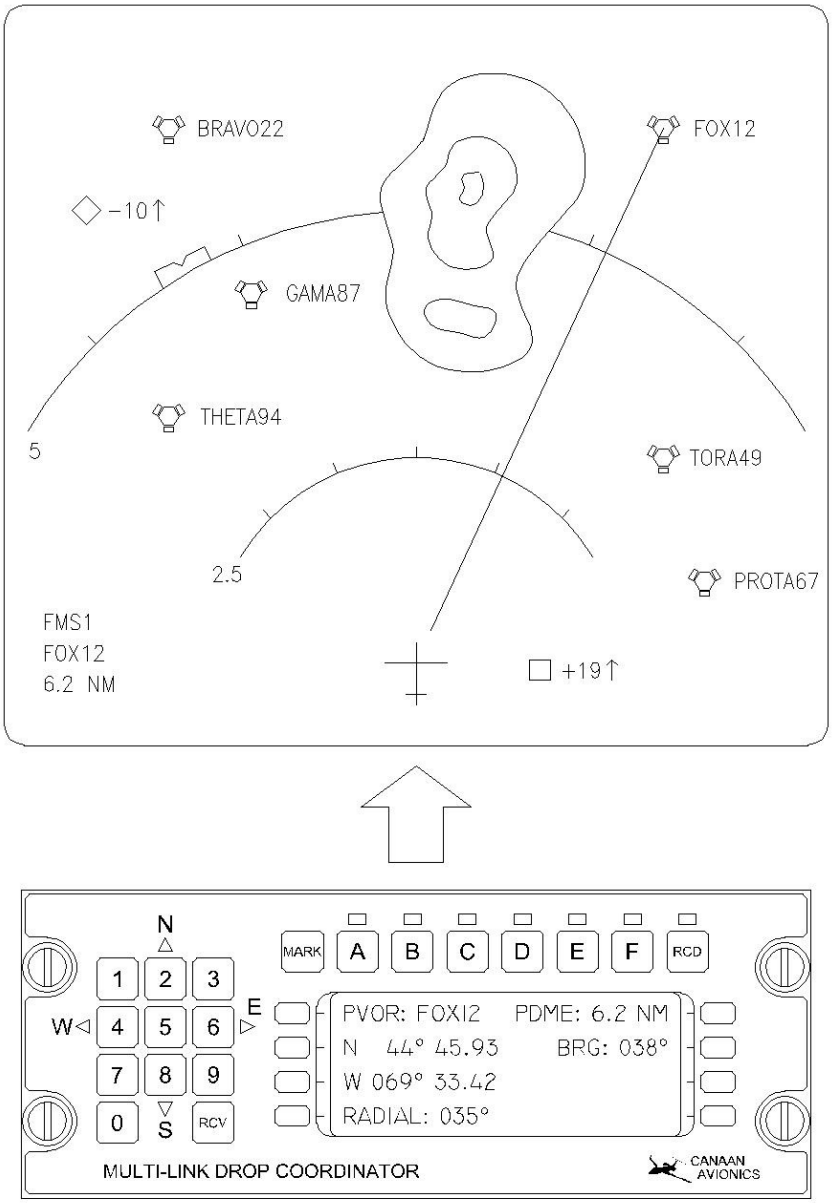

Figure 5, MLDC Interface with Electronic HSI or EFIS Systems

The MLDC sends an ARINC 429 GPS buss with PVOR stations and present position to electronic HSI's and EFIS systems. The PVOR waypoint data is shown on the composite display system along with terrain, weather, and traffic data. This provides the pilot with an all-in-one composite display for superior situational awareness. The MLDC is capable of generating simple flight plans to the various waypoints/drop points and provides roll steering commands to the flight director which steers the aircraft onto the flight plan track.

Mission Example for LRN via Electronic Display: A Lead Plane identifies a fire 'hotspot' by flying over it and marking it with the MLDC. When the pilot presses the 'MARK' button, the MLDC instantly records the latitude, longitude, time, wind speed and wind vector at the drop point as received through the GPS data buss. If the pilot holds down the mark button, the MLDC will also record a desired drop length for the duration of the button press and aircraft track while the button is held will become the desired drop vector. The drop point data is given a unique waypoint identifier (FOX12 for example) and stored into a preset. The Lead Plane pilot can go into the MLDC menus and manually augment any of the drop point parameters if desired.

The Lead Plane sends the drop point, FOX12 through a TCP/IP connection by selecting an aerial assent in a list of preprogrammed tail numbers. The drop point data is sent through the onboard AFF Iridium connection to a C-130 still enroute and to a ground based mission coordinator.

The C-130 pilot receives the drop coordinates like an email in the cockpit and loads it into a preset. The C-130 pilot radios the Lead Plane and aurally confirms that 'FOX12" was received. The wind data attached to the drop point indicates that there is a heavy crosswind from the west so the pilot uses the MLDC menus to move the drop point 100' due west.

The C-130 pilot selects the MLDC as the active NAV source using the EFIS controller and a flight plan is shown on the Multi-Function Display (MFD) from his present position to the FOX12 drop point. The drop point flight plan has an intercept vector that matches the drop vector attached to the waypoint. The pilot then selects 'NAV' on the flight guidance panel and the autopilot guides the aircraft towards the drop point. While flying to the drop point, the pilot monitors the flight plan and ensures that the predicted path of the aircraft does not impede with other aircraft or terrain. All data is displayed to the pilot on the existing MFD display.

Once the drop point is reached the MLDC sets a discrete which illuminates a 'DROP' annunciator to signal the beginning of the drop. The C-130 pilot initiates the drop sequence at that time. The MLDC extinguishes the annunciator once the drop length is reached and the C-130 ends the drop cycle. The MLDC monitors the drop sequence via discrete inputs and records the drop position, vector and length as received through the digital GPS buss.

The C-130 pilot confirms the drop aurally and sends an electronic drop confirmation to either the lead pilot and/or to the mission coordinator using the MLDC.

Calculations for LRN:

Bearing to the PVOR from the present position is expressed by:

$$b_t = a\tan 2\left(\cos(\theta_{y1})*\sin(\theta_{y2}) - \sin(\theta_{y1})*\cos(\theta_{y2})*\cos(\theta_{x2}-\theta_{x1}), \sin(\theta_{x2}-\theta_{x1})*\cos(\theta_{y2})\right)$$

$$b_m = b_t - \Delta_m$$

Where:

θ_{y1} = *GPS position latitude from A429 label 310 (radians)*
θ_{x1} = *GPS position longitude from A429 label 311 (radians)*
θ_{y2} = *drop point latitude from mission controller or manually entered (radians)*
θ_{x2} = *drop point longitude from mission controller or manually entered (radians)*
b_t = *bearing to drop point (radians)*
b_m = *bearing to drop point in reference to magnetic north (radians)*
Δ_m = *magnetic deviation from GPS A429 label 147 (radians)*

Note: Radians used for computation only, user interface is in degrees.

Pseudo DME (PDME) to the drop point is expressed by:

$$T_d = 3437.74677 * a\cos\left(\sin(\theta_{y1})*\sin(\theta_{y2}) + \cos(\theta_{y1})*\cos(\theta_{y2})*\cos(\theta_{x2}-\theta_{x1})\right)$$

$$T_{ds} = \sqrt{T_d^{\,2} + \left(\frac{(A-T_a)}{6076}\right)^2}$$

Where:

T_d = *distance between present position and drop point (Nm)*
T_{ds} = *slant distance between present position and drop point (Nm)*
A = *barometric standard altitude from ADC A429 label 203 (feet)*
T_a = *drop point altitude input by user or received from mission coordinator*

Note: Guidance will be WGS-84 corrected in implementation.

SHORT RANGE NAVIGATION SYSTEM OVERVIEW:

Heavy Airtankers have the advantage of being able to carrying larger loads and a have superior operating range as opposed to single engine and rotary wing aircraft. However, with the larger size, range and capacity comes a significantly lesser ability to maneuver. Larger aircraft typically fly faster during an approach because of higher stall speeds making it harder to target a drop. Because of the limited maneuverability and high approach speeds, heavy aircraft pilots are accustomed to using instrument approach procedures (IFR) instead of visual ones (VFR). The MLDC has the ability to create SRN type approaches to the drop points. The need for SRN flight guidance for drop operations is identified in the *"USFS Very Large Areal Tanker Operational Test and Evaluation Summary Report",* dated March 2, 2009.

There is as high tech precedence for 'GPS only' based approaches at surveyed runways. WAAS/LPV Flight Management Systems are approved to provide lateral and vertical approach guidance all the way down to decision altitude at thousands of surveyed approaches worldwide. The MLDC concept emulates precision GPS approaches and the WAAS/LPV system architecture. The FAA and RTCA have published acceptance criteria for systems which provide precision GPS approaches under TSO-C146a. With some caveats due to the uniqueness of drop operations, the MLDC will conform to this regulatory guidance.

The MLDC can be used to provide aircraft with Short Range Navigational (SRN) approaches in exactly the same way that FMS systems provide precision GPS approaches down to runways. This strategy will enable heavy aircraft (and light aircraft) to fly instrument approaches on a glide path down to a drop point the same way that they do when landing the aircraft on a runway. The differences are as followed:

WAAS/LPV RUNWAY APPROACH	MLDC DROP POINT APPROACH
GPS guidance draws an approach down to a runway (ground altitude).	GPS guidance draws an approach down to a drop point 200-400' above the terrain.
FMS generates pseudo localizer signal which lines up aircraft laterally on the end of a runway.	MLDC generates pseudo localizer signal which lines up aircraft laterally on the drop point vector.
FMS generates pseudo glideslope down to end of runway.	MLDC generates pseudo glideslope down to the drop altitude above a drop point.
Lateral and vertical guidance is per surveyed approach plates.	Lateral guidance is per drop point vector and vertical guidance is based on the drop altitude and a laser altimeter recording.
Approach procedures with WAAS/LPV are exactly like ILS procedures.	Approach procedures with MLDC are exactly like ILS procedures except the landing gear remains up and the decision altitudes are 200-400' higher. A drop point approach always ends in a go-around instead of a landing.

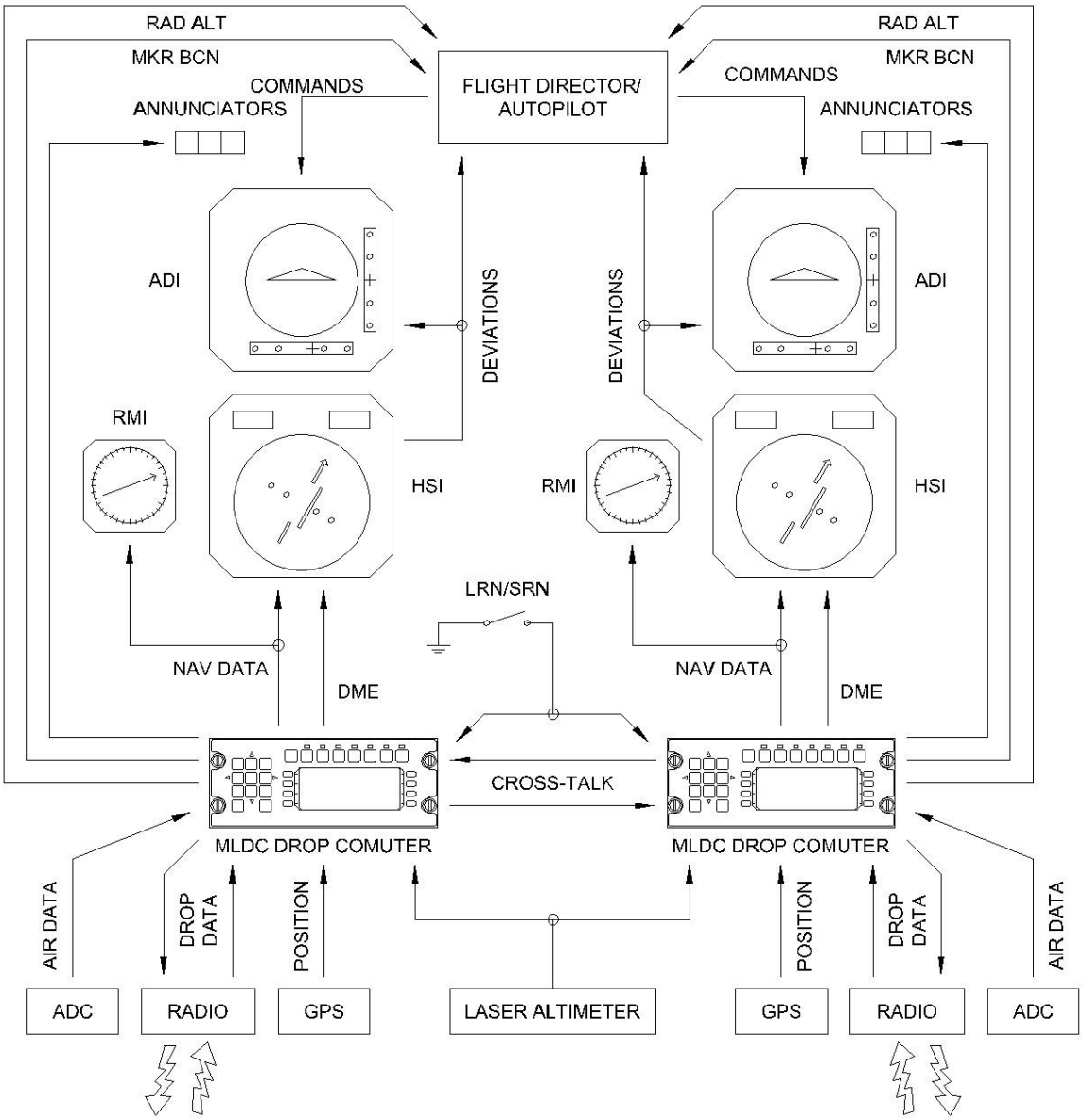

Figure 6, System Block Diagram of MLDC with LRN and SRN Navigation

The MLDC provides SRN when interfaced with WAAS GPS receivers, air data computers (ADC) and a laser altimeter. Dual MLDC's provide cross-talk that compares navigation data off all GPS, ADC and laser altimeters inputs and also compares the individual navigation computations of each MLDC. Along with the drop point bearing, the MLDC will provide Pseudo Localizer (PLOC) and Pseudo Glideslope (PGS) signals for the flight instruments.

The MLDC computes lateral SRN data to the drop point when in SRN mode. The crew places the MLDC into SRN mode using an external switch or by selection approach on the flight director (depending on installation). The MLDC computes Pseudo Localizer (PLOC) based upon the drop coordinates and drop vector. Pseudo marker beacon signals are generated when distance to the drop point reaches 5 nm (POM), .6 nm (PMM) and 200 feet (PIM).

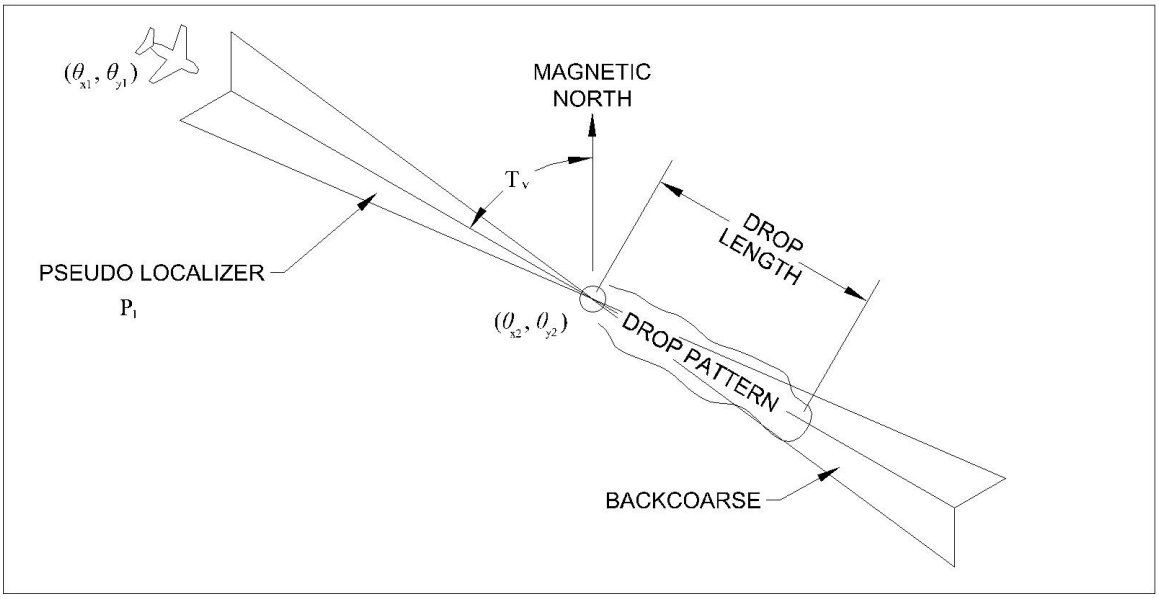

Figure 7, Pseudo Localizer (PLOC)

The MLDC computes vertical SRN data to the drop point when in SRN mode. The MLDC computes Pseudo Glideslope (PGS) based upon the distance to go, drop altitude, aircraft altitude and selected glide path angle. The aircraft will fly the PGS down to the drop point. The PGS will be flagged when the drop point is reached/passed and the aircraft will go around.

The MLDC creates a Pseudo Radio Altitude (PRA) and pseudo marker beacons for use by the autopilot/flight director. The PRA and pseudo marker beacon signals are switched into the autopilot when the MLDC is the active NAV source. Radio altitude display to the flight crew is not affected. PRA and pseudo marker beacon signals are generated because most autopilots use radio altitude and marker beacon to compensate for localizer and glideslope convergence during the approach. The PRA signal is compensated for the drop altitude and the pseudo marker beacon signals are preset along the approach radius. The original radio altitude and marker beacon signals are switched back to the flight director when the MLDC is not the active NAV source.

The MLDC will not provide SRN guidance unless the Go Around Advisory function is active; *see next section for GA Advisory*. Each MLDC will compute and crosstalk the PGS data. Neither MLDC will validate the approach unless both approach solutions match.

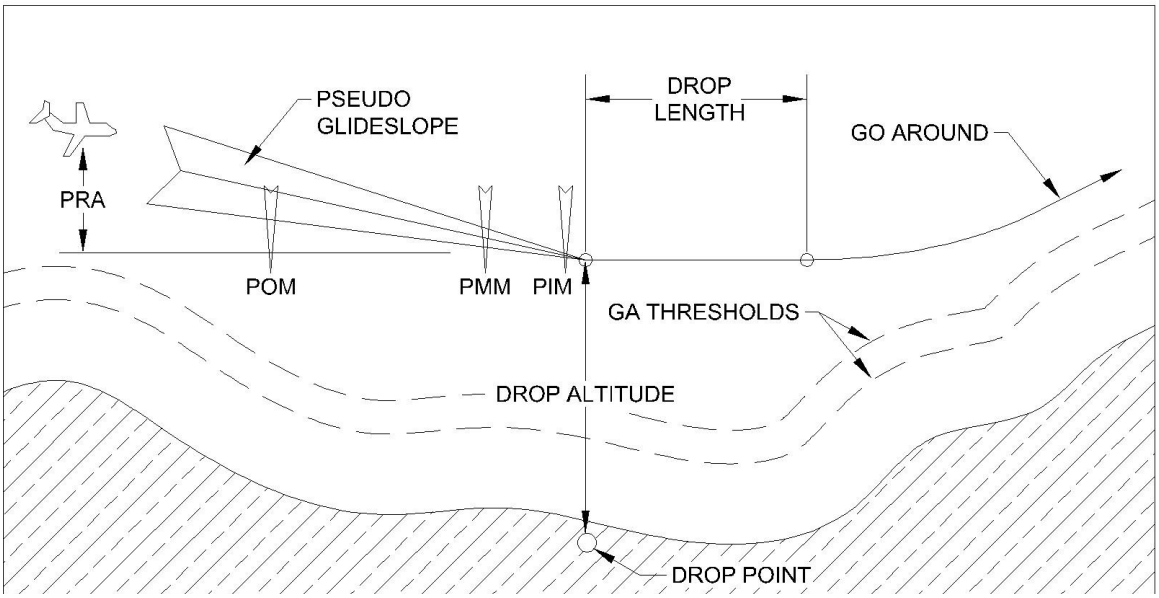

Figure 8, Pseudo Glideslope with Terrain Profile

Mission Example for SRN Approach: A Lead Plane has already selected and sent a drop point to a heavy aircraft through the MLDC. The heavy pilot selects the MLDC as the active NAV source and the flight director guides the aircraft over the drop point along the desired radial.

The aircraft flies over the drop point along the drop vector anywhere from 1500-2500' above the terrain (see **Figure 9**, Item 1). The pilot monitors the laser altitude display and ensures that the aircraft is flying high enough above the terrain so that the TAWS system is not issuing terrain alerts and low enough so that the laser altimeter is able to maintain a ground altitude reading. At this time, the MLDC records a ground altitude script which enables the GA Advisory and SRN mode.

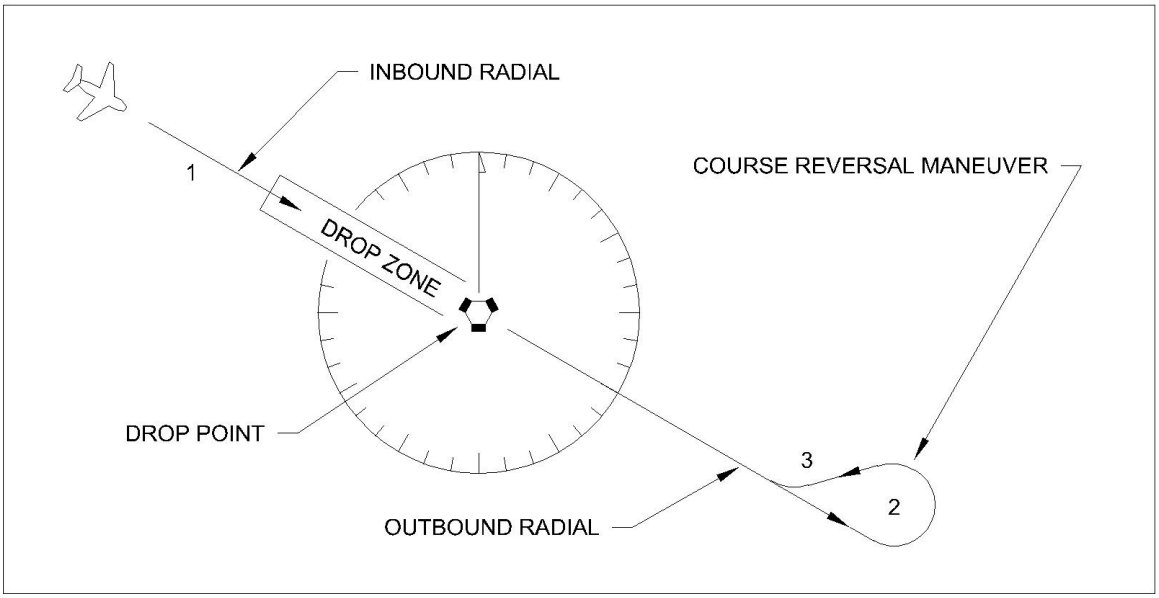

Figure 9, LRN Pre-Approach Procedure

The pilot performs a course reversal maneuver (Item 2) and lines up the aircraft onto the drop point vector (Item 3). The MLDC has enabled short range guidance (SRN) and the pilot selects APR (approach) on the flight director. The MLDC removes LRN data and provides PLOC, which will center as the pilot aligns to the drop vector, and a PGS, which is full scale up because the aircraft will typically be under the glide path when far away from the drop point (Item 4, next page). The MLDC provides PLOC guidance based on the drop point vector and distance-to-go and PGS guidance based on the distance-to-go, drop altitude, glide path angle.

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The crew inhibits the TAWS system before the descent to prevent aural terrain warnings. The glideslope pointer begins to center and the aircraft begins the approach. Just before the top-of-decent the POM beacon illuminates (Item 5). The crew initiates the decent and centers the glideslope pointer (Item 6). The PMM marker beacon illuminates (Item 7). Just before the drop point is reached, the PIM marker beacon illuminates and the 'DROP' annunciator flashes which signals to the crew to level off the aircraft and prepare for the drop sequence (Item 8). The drop point is reached and the 'DROP' annunciator stops flashing and illuminates steady. At this time the PGS is flagged and the crew initiates the drop (Item 9). The crew flies back course guidance during the drop sequence (Item 10). The 'DROP' annunciator extinguishes when the aircraft reaches the end of the drop (Item 11). The aircraft climbs out along the outbound drop point radial. It is safe to leave the PLOC backcourse once the aircraft gains sufficient altitude and the TAWS system is re-enabled (Item 12).

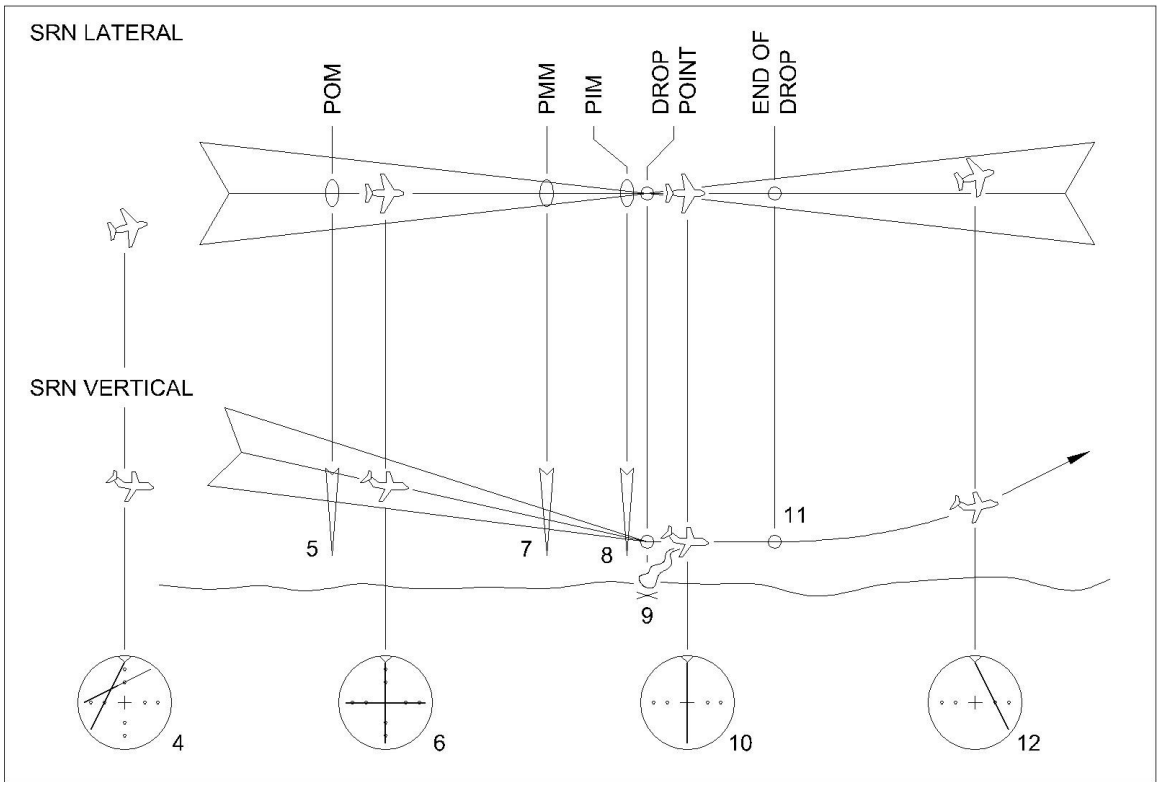

Figure 10, SRN Approach Procedure

In this scenario, the tanker aircraft records the ground altitude script. An alternative means for the ground altitude script is for the Lead Plane to record the altitudes and then send the altitude script to the tanker thru the MLDC data link. Then the inbound tanker could simply fly the approach using the pre-recorded script. This eliminates the need for procedure Items 1, 2 and 3 (**Figure 9**).

Calculations for SRN (See **Figure 7 & 8**):

Pseudo localizer (PLOC) for the drop point approach is expressed by:

$$P_l = (T_v - b_m) * 3.55234$$

Where:
P_1 = *pseudo localizer along drop vector (DDM)*
T_v = *drop point vector input by operator (radians)*

Pseudo glideslope (PGS) for the drop point approach is expressed by:

$$P_g = \frac{\left(a\cos\left(\frac{T_d}{T_{ds}}\right) - T_g \right) * 63}{\pi}$$

Where:
P_g = *pseudo glideslope towards the drop point (DDM)*
T_g = *select glidepath angle (radians)*

Pseudo Radio Altitude (PRA) for the flight director is expressed by:

$$P_r = A - T_a$$

Where:
P_r = *pseudo radio altitude to drop altitude (feet)*

Note: Guidance will be WGS-84 corrected in implementation.

GO AROUND ADVISORY OVERVIEW:

The GA Advisory function is a progressive annunciation that advises the air crew to climb pending terrain. The MLDC uses recorded laser altitude along a predetermined PVOR radial to provide an automatic look-ahead terrain indication. The GA Advisory function is not intended to replace the onboard TAWS system. The GA Advisory function is supplemental and provides Go-Around advice only. The GA Advisory must be active in order for the MLDC to provide SRN guidance.

The GA Advisory function will provide decisive vertical situational awareness which is tailor made for firefighting aircraft. The GA advisories provide clear vertical situational awareness when TAWS alerts are disabled. The GA Advisory function will not routinely issue GA cautions or warnings. GA warnings and cautions are designed to direct the crew's attention towards terrain avoidance, aircraft power setting and stall envelope.

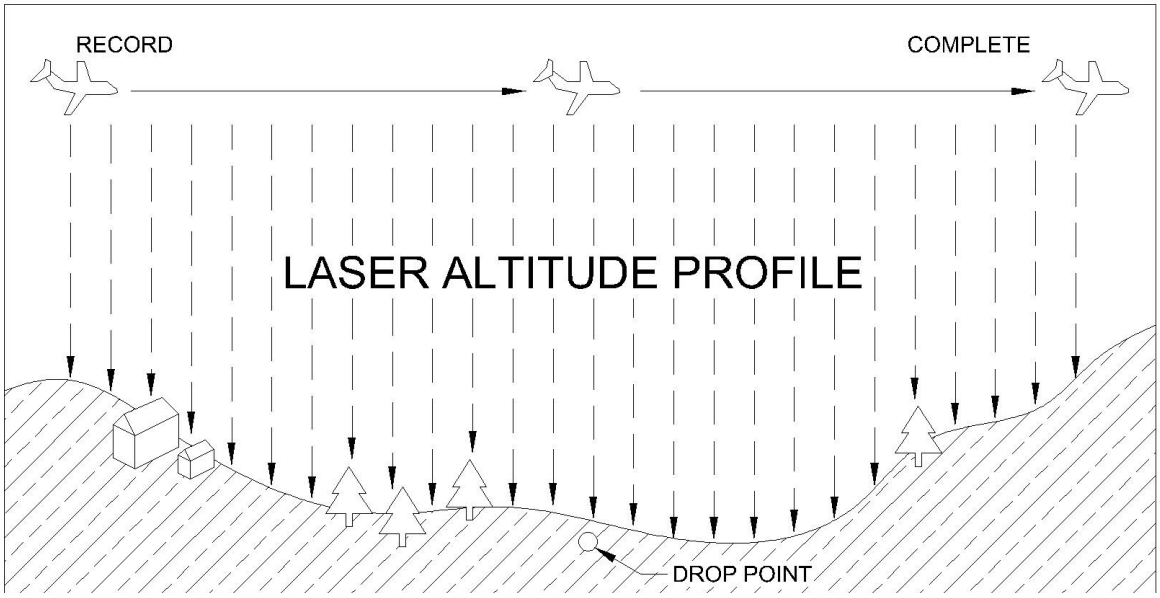

Figure 11, Terrain Recording, Ground Altitude Script

To enable the GA Advisory, the crew must make a preliminary flight along the PVOR radial (as shown in **Figure 9**, Item 1). This allows the MLDC to record the worse case laser altitudes along the radial while the aircraft passes well above the terrain. The MLDC will automatically compute a ground altitude script based on the laser altitude signal and the GPS/ADC altitude. The MLDC stores the ground altitude script with the associated drop point and drop vector.

Two separate MLDC's will use two separate GPS's, ADC's and the laser altimeter to produce two separate ground altitude scripts. The MLDC will cross-talk each script to ensure that there is no corruption. The GA Advisory thresholds are then set using the ground altitude script and the worst case climb performance of the particular aircraft (**Figure 12**).

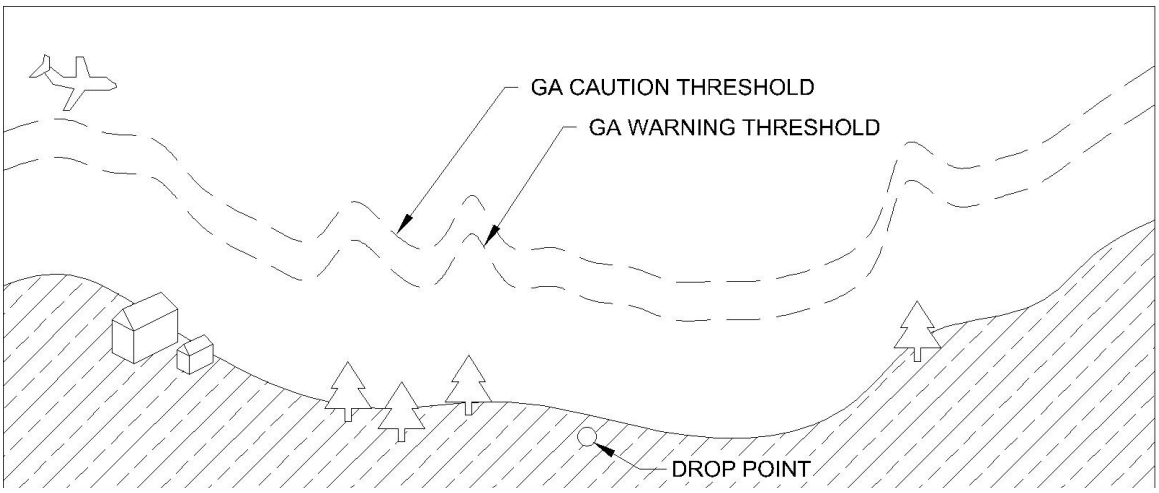

Figure 12, GA Thresholds

The MLDC keeps two vertical thresholds; a GA Caution Threshold, and a GA Warning Threshold. The MLDC continuously projects a virtual flight path ahead of the aircraft which represents the path that the aircraft is expected to fly given the aircraft's airspeed, vertical speed, specific G-limited climb maneuver, and worst case climb performance.

The MLDC is configurable for aircraft specific G-limiting and climb performance expectations which are commiserate with those identified by the aircraft's engine-out performance, Type Certificate Data Sheet, and existing Structural Integrity Programs.

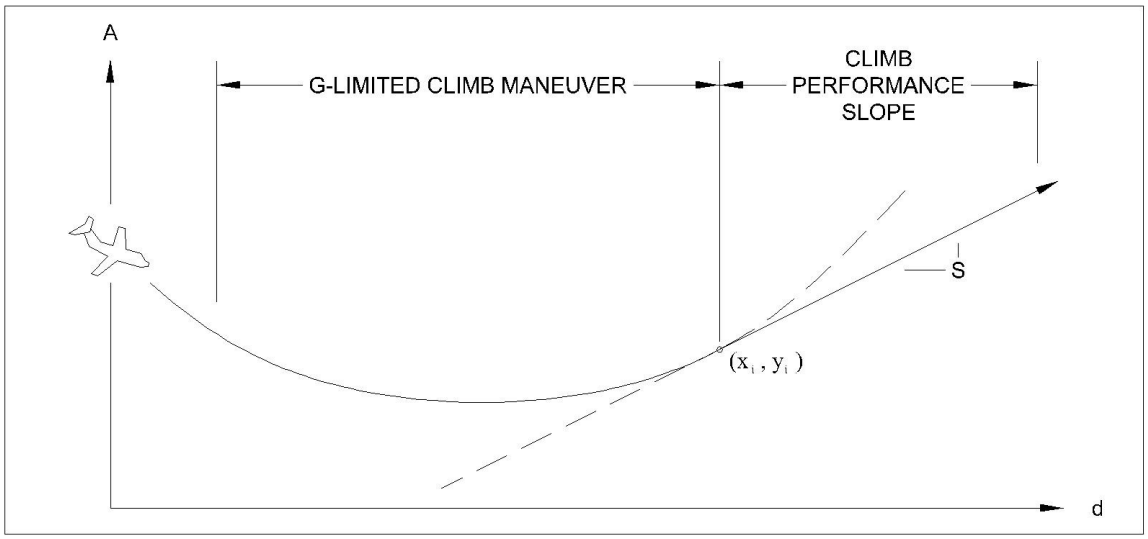

Figure 13, Climb Projection

The MLDC will issue an amber GA Caution if the aircraft climb projection falls below the first threshold. The GA Caution distance from the terrain is strapped into each MLDC and is aircraft specific. Each MLDC will issue a GA Caution when the climb projection falls under any point in the altitude script 'plus' the GA Caution Threshold.

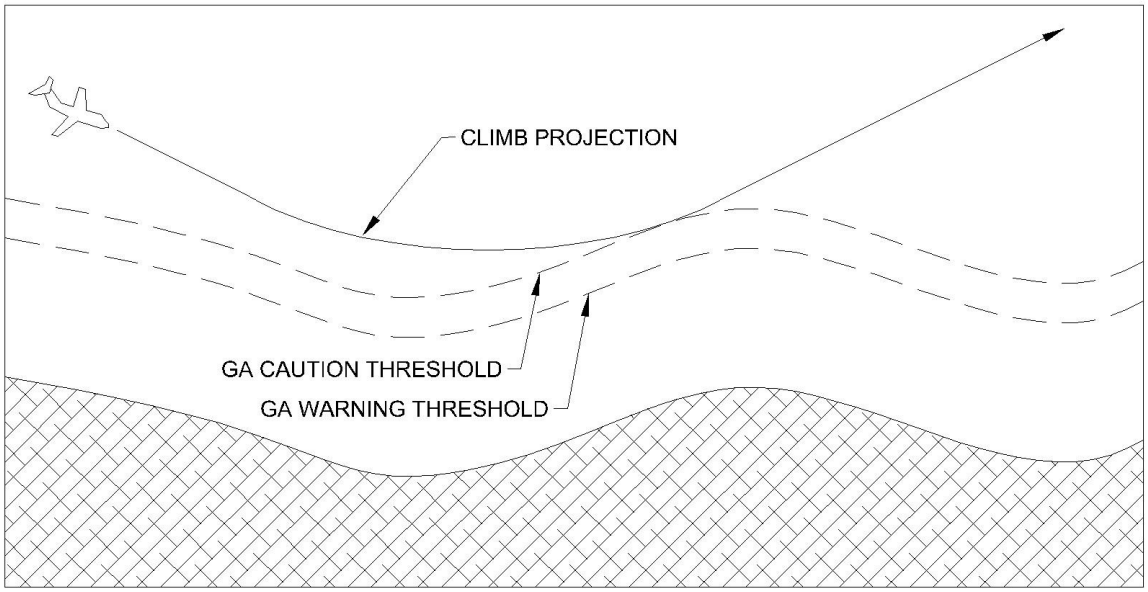

Figure 14, GA CAUTION Scenario

The MLDC will issue a red GA Warning if the aircraft falls below the second threshold. The GA Warning distance from the terrain is strapped into each MLDC and is aircraft specific. Each MLDC will issue a GA Warning when the climb projection falls under any point in the altitude script 'plus' the GA Warning Threshold.. Warning and Caution logic is logically OR'd between all installed MLDC's.

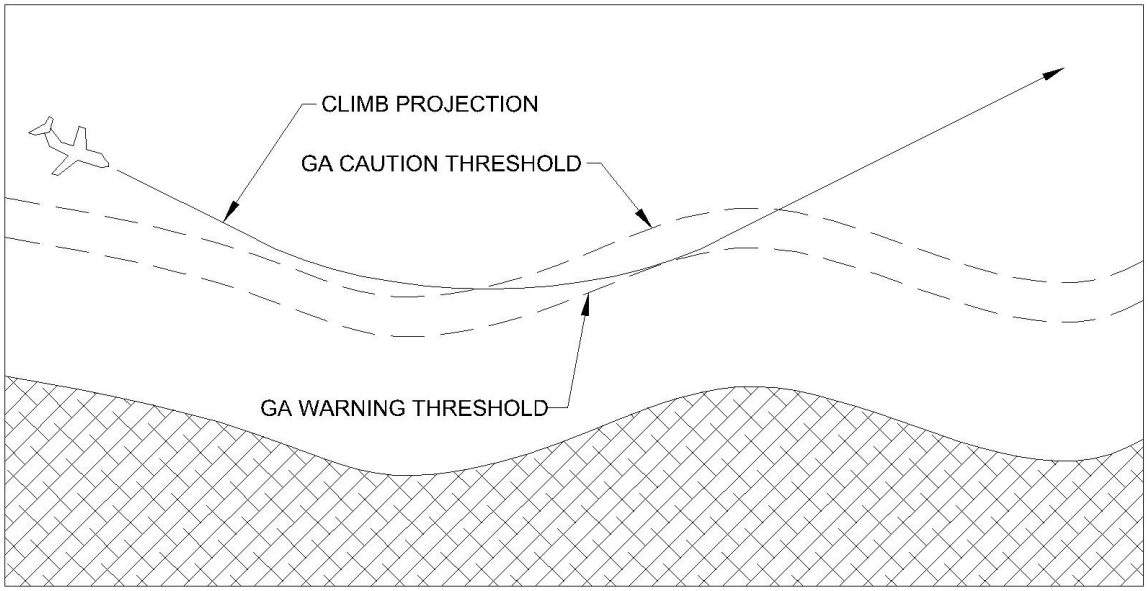

Figure 15, GA WARNING Scenario

Once the MLDC has recorded the ground altitude, the crew can fly an approach using SRN guidance from the MLDC. The MLDC will monitor the ground altitude script during the approach and ensure that the laser altimeter, the GPS position and integrity levels, and the air data inputs mathematically patch the previously recorded ground altitude script.

In the event that the calculated drop approach is not possible, the MLDC will not validate the approach guidance. This occurs when the drop glide path or subsequent climb-out projection are within the GA Caution threshold. This prevents the crews from performing a guided approach that could result in CFIT.

The MLDC will immediately issue a GA Caution or Warning if any of the following is true:

- The flight crew is not flying on the same radial to which the terrain recording was made. A GA Caution/Warning is issued to prevent the aircraft from flying low over terrain that was not recorded by the laser altimeter.
- Monitored systems fail or report contrary data (GPS, ADC, radio altimeter, and ground altitude script). The data is monitored during the ground altitude recording and during the approach sequence to eliminate the possibility of data corruption.
- Cross-side MLDC miscompare. The MLDC architecture must include a diverse means of approach guidance computation to eliminate the possibility of misleading SRN guidance.

Calculations for GA Advisory (See **Figure 13**):

G-limited maneuver projection is expressed by:

$$A = \frac{d^2 * 11.2944 * (g-1)}{K^2} + \frac{d * V}{101.267 * K}$$

Where:

A = *projected altitude ahead of aircraft (feet)*
d = *projected distance ahead of aircraft (feet)*
g = *maximum g-load during maneuver from hard straps (G's)*
K = *airspeed from ADC A429 label 206 (knots/hour)*
V = *vertical speed from ADC A429 label 212 (feet/min)*

Distance to climb performance slope intercept is expressed by:

$$x_i = \frac{S * K^2}{22.5888 * (g-1)} - \frac{V * K}{2287.51 * (g-1)}$$

Where:

x_i = *projected start of climb (feet)*
S = *worst case climb performance slope from hard straps (feet altitude/feet distance)*

Altitude at climb performance slope intercept is expressed by:

$$y_i = \frac{K^2 * S^2 + 8.62545^{E-8} * K * S * V - 9.75134^{E-5} * V^2}{45.1776 * (g-1)}$$

Where:

y_i = *projected altitude at start of climb (feet)*

Y-axis intercept for climb performance slope intercept is expressed by:

$$i = \frac{K^2 * S^2 - 1.97498^{E-2} * K * S * V + 9.75134^{E-5} * V^2}{45.1776 * (g-1)}$$

Where:

i = *y-intercept (feet)*

Laser Altimetry is essential for recording accurate ground altitudes and the aircraft which creates the ground altitude script must be retrofitted with an approved laser altimeter. Most aircraft are equipped with Radio Altimeters. The chief difference between laser and radio altimeters is in their ability to measure dry vegetation (see **Figure 16**). Laser Altimeters register the tree tops whereas radio altimeters penetrate vegetation and reflect off the forest floor. Unfortunately, most all topographical survey data is recorded using radio [aka radar] altimetry. Conventional TAWS systems are able to use the radio-derived terrain data because commercial aircraft never descend towards wooded terrain. Airports are always surveyed for trees and obstacles.

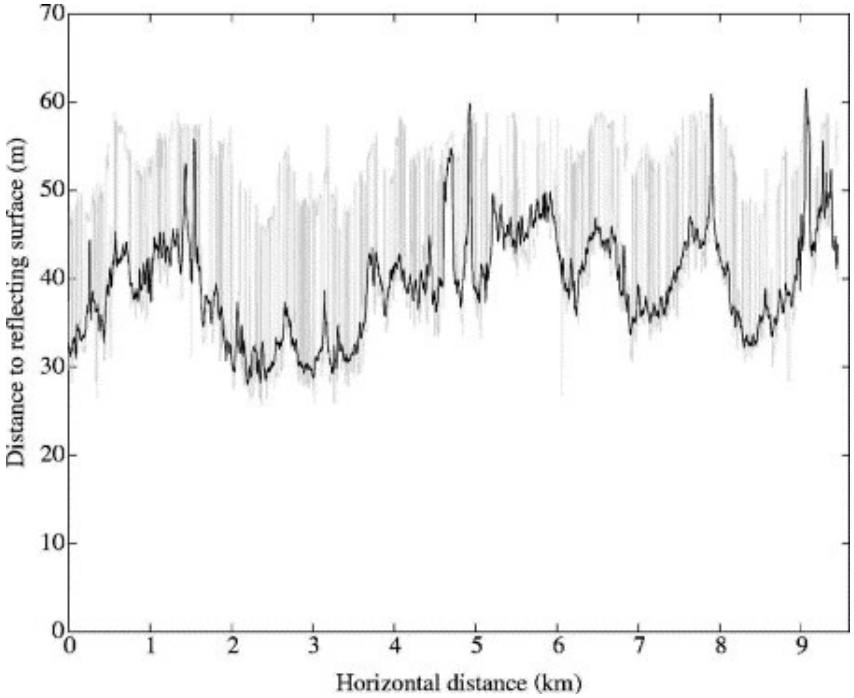

Figure 16, Laser Altimeter [Grey] vs Radio Altimeter [Black] in Forest
Source: College of Oceanic and Atmospheric Sciences, Oregon State University, 2001

There are many commercially available Laser Altimeters for aircraft. Commercial land-surveying companies have furthered the concept beyond single distance measurement to create accurate 3D images of terrain from moving aircraft. For the purpose of the MLDC, the laser altimeter will provide a simple terrain profile along a drop approach course fix.

SYSTEM DEVELOPMENT STRATEGY:

Phase I, Hardware In the Loop Simulation
Canaan Avionics intends to develop the MLDC using a flight simulator. There the hardware and software can be developed while using simulated GPS, air data, and laser altitude sensors and tested in a simulated operational environment.

Phase II, Field Testing
Once the hardware and software are developed, Canaan Avionics will need to prove the design on an actual aircraft. A small flight test program will be required to iron out technical problems not resolved in the lab. This will also provide a valuable opportunity to fine tune the design for the pilots in the field.

Phase III, Certification:
The MLDC's will go through DO-160 and DO-178 testing to insure that they are airworthy designs. The first aircraft to receive MLDC's will need to be STC'd to ensure that their installation and operation is airworthy as well.