

## Case Studies for the verification system of UAVs Flightplans

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### Abstract

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#### Keywords:

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Ascribable to the progressively complicit of the Unmanned aerial vehicle (UAV) mission planning, verification tools are needed to support the deviser to verify the manual flight plan and to make sure it's free from faults which can result in losses of the vehicle itself. In this paper, we tend to bring out three case studies to envision and verify the flight plan entered manually by users through the machine-controlled Mission Planning System, a report with needed corrections, if required, are provided.

The three check cases that conferred in our paper includes a report for each case, an initial case could be a traditional case without mistakes, the other two cases show however mistakes seem within the report provided. We induce a tendency to desire this approach serves to scale back human error throughout the preparation of UAVs missions.

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## 1. Introduction

In general, UAVs are either controlled by a pilot operating a remote control or by an embedded computer. [1], [2], [3].

Unmanned aerial vehicle (UAV) intelligence, surveil, and reconnaissance (ISR) missions are getting more and more complicated. Whereas within the past, several operators worked together to plan missions for a single UAV, a single operator is now expected to plan missions for multiple UAVs. This paradigm shift has been enabled by the multiplied use of autonomy, e.g. autopilots that can execute. [4]

Low-level tasks like flying between waypoints, loitering over targets, surveying roads, and monitoring patrol routes.

For this shift verification of the flight plan is very necessary to find out the ordinances and be sure no violations are found. The proposed model is then checked or verified against the specifications using an automated tool which explained in this paper. For each violated specification, the model checker outputs a counterexample that demonstrates how the violation occurs. Given these similarities, it seems likely that formal methods such as model checking could also have useful applications. [5]

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In the UAV mission planning domain. For example, if the goals and constraints of mission-tasks that have to be coordinated, areas that must be surveilled in a particular order, regions that must be avoided – can be formalized into specifications, and if UAV behaviors can be represented as finite state models, then model checking could be used as a tool to help operators verify mission plans and reason about errors using counterexamples, as shown in the second case study which verifies violation of some restricted areas.

In this paper the introduction is the first section, we secondly review the associated work in UAVs mission planning. In the third section, the interface modules of the Proposed AMPS for UAV have been surveyed. In the fourth section, we handle three case studies for verification of the mission plan. Finally, we tend to conclude with a discussion of areas of interest for future work.

## 2. Related Work

Biabani et. al. Proposed in their paper [6] a computer-based system for UAV mission planning. The advances in developing such a system are to examine the possibility to utilize and integrate several problems solving models and techniques in an integrated intelligent and traditional environment. The proposed system uses an integration of Multi-Agent System (MAS) and Common KADS (Knowledge Acquisition and Documentation, Structuring) methodologies obtain accurate mission planning system. [16], [17].

Thiago et. al. Evaluate in [7] the mission planning for UAV from intralogistics point of perspective. They employ an optimal measure to compare with a pre-computed value of a mission cost. They present a methodology that measures the cost of mission planners for a commercial UAV. [14]

In [8] Laura R. Humphrey et. al. Appraise the conventional methods to troubles in robot control and multi-agent planning and discuss how related techniques can be expanded to serve as the foundation for improved human automation UAV intelligence, surveillance, and reconnaissance (ISR) mission planning systems. [15]

E. Santamaria et. al. In [9] propose a new mechanism with semantically richer constructs that will enable the end user to specify more complex fight plans. The proposed formalism provides means for specifying iterative behavior, conditional branching, and other constructs to dynamically adapt the fight path to mission circumstances. Collaborating with the FCS, a replacement module onboard the UAS is accountable for executing these plans. The paper additionally presents a paradigm implementation of this module and also the results obtained in simulations.

In [10] Carlo Di Benedetto et. al. investigate the flight planning for unmanned aerial vehicles. They propose a prototype of preflight planner for different models of unmanned aircraft. The planner is able to take into account several constraints (e.g., the vehicle dynamics, the no-fly zones, the endurance, the feasibility of the mission objectives, the terrain separation, etc.). It also provides a quantitative estimation of the air data link coverage and of the National Imagery Interpretability Rating Scale (NIIRS) index for the image quality. An overview of the prototype is reported and some significant test results are discussed in order to show its features.

David H. Lopez et. al. In [11] develop software which performs multiple tasks related to aerial Photogrammetry and particularized to UAV systems.

Specifically, the flight designing and management framework incorporate a sturdy geometric management that guarantees the effectiveness, precision, and reliableness of image acquisition. A true case study was generated to check and validate the flight planning and management methods developed here.

## 3 . Proposed AMPS for UAV Overview

In paper [6], a system for verification of flight arrange for midrange UAV (model 324) has been projected together with the methodologies accustomed to integrating Multi-Agent System and customary KAD System Methodologies to induce correct verification for the flight plan. The system has been referred to as automatic Mission Planning System.

During this section, we tend to present the interface modules as well as a pre-mission aids module, a mission calculation module, and emergency cases modules as a preface to the future section that deals with three case studies. [12], [13]

### 3.1 AMPS interfaces modules:

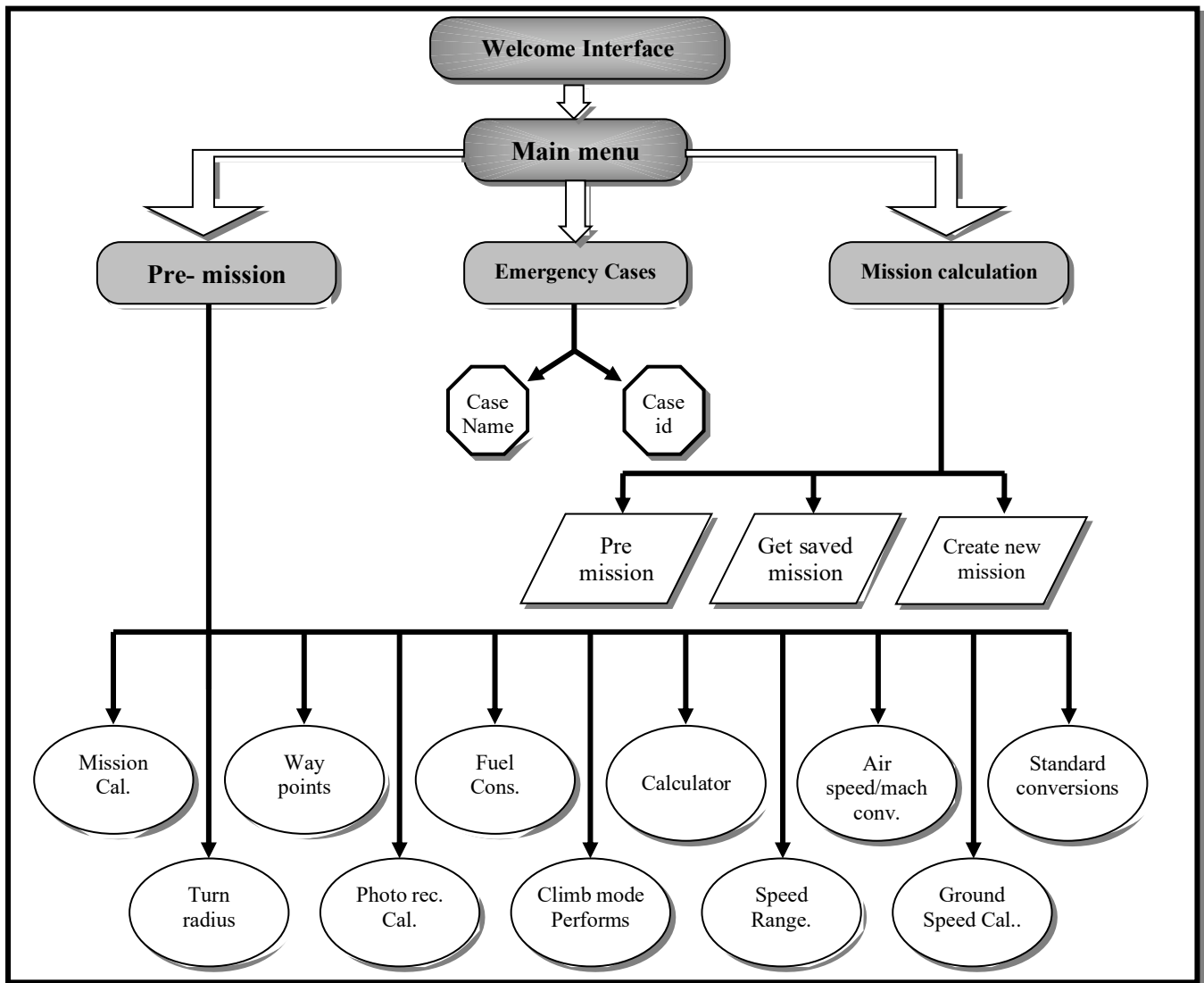


Figure 1 . Hierarchy for AMPS interfaces

**3.2 Pre-mission Aids interface:** It includes thirteen choices as follows: figure 2, 3 show some used algorithms.

**3.2.1 Standard Conversion:**It supports the most conversions for lengths, weights, and liquids.

**3.2.2 Ground speed calculation:** It provides the user with the real ground speed from actuality airspeed when considering the wind effects.

**3.2.3 Airspeed / Mach Conversion:**To support the conversion between physicist speed and Airspeed.

**3.2.4 Speed variables at a certain altitude:** provide speed limit of the vehicle at totally different altitudes.

**3.2.5 Calculator:** Works as a customary and scientific calculator.

**3.2.6 Climb mode performance:** To calculate the performance of the vehicle throughout the climb mode.

**3.2.7 Fuel consumption:**To calculate the consumption of the fuel throughout numerous modes: climb, straight and dive modes.

**3.2.8 Photo reconnaissance calculation:**To provide all the information regarding the image calculation.

**3.2.9 Waypoints calculation:** Provides distance and direction between 2 points (given) or provides the user with some extent at any distance and direction from a given waypoint.

**3.2.10 Turn radius:** To calculate the radius of a flip of the vehicle at totally different altitudes.

**3.2.11 Mission calculation:** To transfer between pre-mission aids and mission calculation.

**Sub WP Calculation Command- Click**

```

Inputs          Deg  Min  Sec
First Latitude as  N  30   40  50 = L1
First Longitude as E  29   30  50 = X1
Second Latitude as -  -    -   - = L2
Second Longitude as -  -    -   - = X2

Transaction
  Convert every WP Into Decimal
  Like 30 + 40/60 + 50/3600 = 30.6856
       29 + 30/60 + 40/3600 = 29.5111
  Distance =
     $60 \cos^{-1} [\sin L1 \sin L2 + \cos L1 \cos L2 \cos (X2-X1)]$ 
  Heading =
     $\cos^{-1} [\sin L2 - \sin L1 \cos (D/60) / \sin(D/60) \cos L1]$ 
  Outputs  Show Distance Show Heading
End Sub

```

Figure 2. Shows algorithm for waypoints calculation

```

If ALT(wpx) > ALT(wpx+1) Then
  Tan (dive angle) = (difference between two heights) / (distance)
  If TAN > 1 Then
    ANGLE = (TANO)-1 * 180 / 3.14159266535898
    angle1 = Int (ANGLE)
    ANGLE2 = Int((ANGLE - angle1) * 60)
    Angle3 = Int(((ANGLE - angle1) * 60 - ANGLE2) * 60)
    Prm = "Dive angle = " & angle1 & " " & ANGLE2 & " " & angle3 & " > 45 " & vbCr
    Prm = Prm & "To correct this ERROR you can :" & vbCr
    Prm = Prm & "Reduce first Altitude" & vbCr
    Prm = Prm & "Increase second Altitude" & vbCr
    Prm = Prm & "Increase distance between the two points" & vbCr
    Prm = Prm & "Do you want to correct ERROR now ?"
    Til = "Error" ... End If

```

Figure 3 . shows algorithm for dive angle calculation

**3.3 - Mission calculation interface:** Example of rules employed in this part is given in figure-4.

This interface has four main choices:

**3.3.1 Create new mission:** It accepts the data for a new mission.

**3.3.2 Get saved mission:** From that, a saved mission might be retrieved.

**3.3.3 Pre-mission Aids:** Give the potential to transfer between mission calculation interface and pre-mission aids interface to support the user with necessary facilitate throughout the planning of a new mission.

**3.3.4 Return:** To come to the main menu.

1. If total number of way points is less than or equal to 80 points then mission is accepted.
2. Trip will be successful if the used fuel is less then 90% of total fuel capacity.
3. If WP<sub>x</sub> (height) less than WP<sub>x+1</sub> (height) then mode equals climb or if WP<sub>x</sub> (height) more than WP<sub>x+1</sub> (height) then mode equals dive else mode equal straight.
4. If Distance between WP<sub>x</sub> and WP<sub>x+1</sub> is less then minimum leg Distance then either WP<sub>x</sub> or WP<sub>x+1</sub> is not accepted.
5. If Dive angle between WP<sub>x</sub> and WP<sub>x+1</sub> is more than 45° then WP<sub>x</sub> (height) should be decreased or WP<sub>x+1</sub> (height) should be increased or Distance between WP<sub>x</sub> and WP<sub>x+1</sub> should be increased. where dive angle is the angle between flight path and ground surface

Figure 4 . Example of rules

### 3.4 Emergency Cases Area

The inference knowledge behind emergency cases area merely represents the cover and differentiate diagnostic technique that is referred to as a diagnostic module.

Cover and differentiate contain principally two inference steps. Initial is cover that gets a complain and generates a set of hypotheses associated with it. Second is differentiating that gets the generated hypotheses yet as some extra observation to spot the emergency standing and the way to modify such emergency. Figure Five represents the emergency case symbol inference structure.

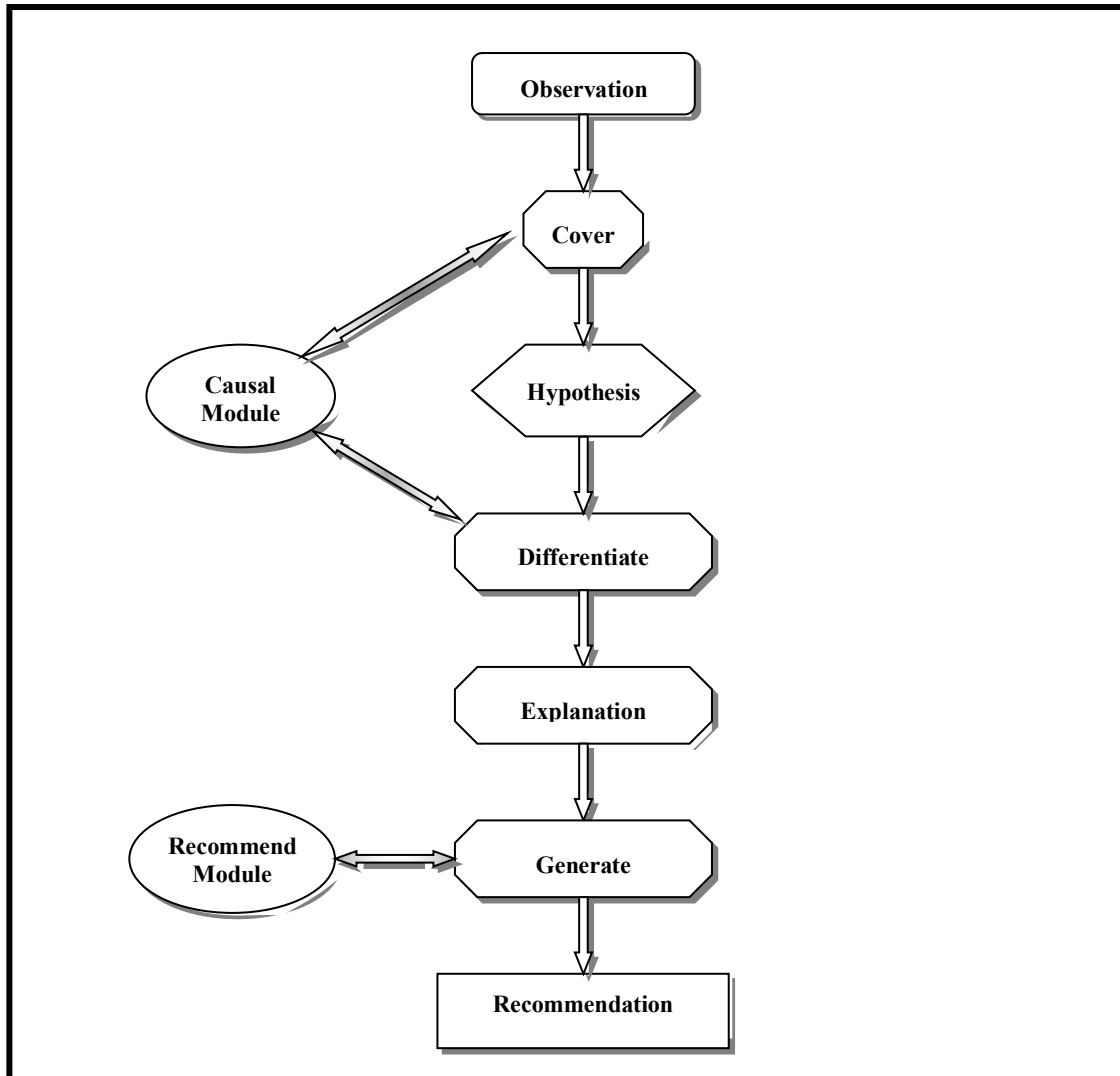


Figure 5. Emergency case identifier inference structure

## 4 . Case Studies for The AMPS

This section introduces 3 case studies, the initial case deals with a normal mission, the second handles the case of violation of restricted areas and also the third case shows an emergency case. Every case includes objective, inputs, results, and comment. Main report and report of errors if found are shown as figures.

### 4.1 Case one: Normal Mission

It is a straightforward and normal case with none violations of the restrictions on the vehicle, rules, or restricted areas.

#### 4.1.1 Objective of case one

The objective of this case is to verify the conventional operation of AMPS and to make certain that it accepts mission data and saves it in a normal and safe manner. Additionally to confirm that the report is written with the desired data and shape. The appearance of the sentence (Mission has been successfully calculated) means that correct mission.

#### 4.1.2 Inputs

The input data are entered through “create a new mission” interface for mission calculation menu. Figure six shows the interface of getting into data. The input data are merely eight-way points beginning with zero and ending with seven. Every waypoint includes its latitude, longitude, altitude in meter and also the modes as follows:

- \* **Climb** if the height of the present waypoint is smaller than the height of the next waypoint.
- \* **Straight** if the height of the present w. point is equal to the height of the next w. point.
- \* **Dive** if the height of the current waypoint is smaller than the height of the next waypoint.

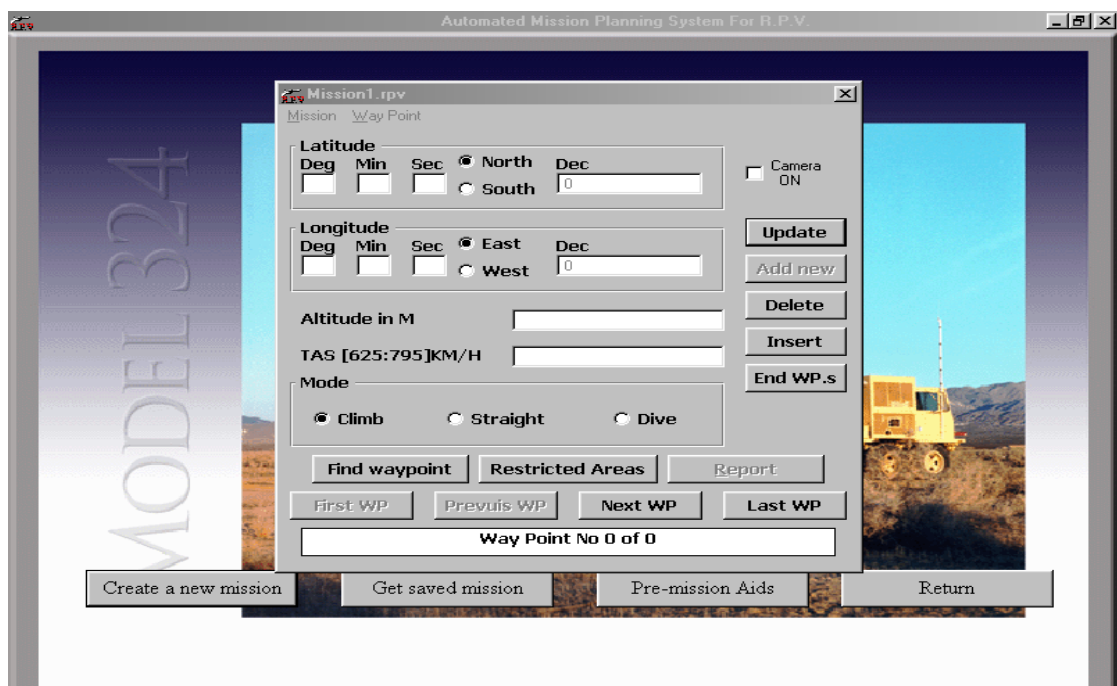


Figure 6 . The interface for entering mission data

AMPS will show the limitation of the airspeed due to the performance curvatures and the tables of the vehicle which were stored previously. Figure 7 shows the input data in case one.

W.p. #	Latitude	Longitude	Mode	Altitude
0	N 29 03 45	E 30 53 45	Climb	10
1	N 29 04 30	E 30 45 50	Climb	6000
2	N 29 04 00	E 30 38 10	Climb	6000
3	N 30 01 45	E 30 25 00	Straight	6000
4	N 30 09 00	E 30 39 00	Dive	6000
5	N 29 05 00	E 30 54 00	Dive	4000
6	N 29 04 00	E 30 38 10	Straight	2500
7	N 29 03 00	E 30 51 50	Straight	2500

Figure 7. The input data for case one

AMPS allows the update, delete, and insert of new waypoints. After entering each waypoint data, the data should be updated and at the end of entering all waypoints data (End waypoints), they should be ordered.



A message of end data will appear to ask the user if he is sure or not. If yes, another message will appear to check ERRORS. If yes, the message of “ there is no ERROR” will appear to declare that all calculations have been performed successfully.

#### 4.1.3 Results

The previously mentioned message “ there are no ERRORS” may consider the result. But we can obtain more details by asking for a report. Figure 8 shows the format of the report and its data. As it appears, AMPS calculates the distance of every leg (between every two waypoints), direction and fuel used.

Report for mission Case_one.rpv																	
Mission date :																	
Current date :																	
WP	Latitude			Logitude			Alt	TAS	Mode	Heading	Dist	A_dist	Time	A_time	F_usd	R_rem	Wght
0	N	29	33 45	E	30	53 45	10	709.00	Climb	318.42	0.00	0.00	0.00	0.00	7.00	493.00	1293.00
1	N	29	41 30	E	30	45 50	2555	690.00	Climb	318.44	19.36	19.36	1.68	1.68	11.10	481.90	1281.90
2	N	29	49 0	E	30	38 10	4346	759.00	Climb	318.22	18.65	38.01	1.47	3.15	9.03	472.87	1272.87
3	N	30	1 45	E	30	25 0	6000	884.50	Straight	59.04	31.73	69.74	2.15	5.30	11.93	460.94	1260.94
4	N	30	9 0	E	30	39 0	6000	884.50	Dive	144.12	26.14	95.88	1.77	7.07	8.93	452.01	1252.01
5	N	29	51 0	E	30	54 0	4000	857.50	Dive	261.78	41.15	137.03	2.87	9.94	6.99	445.02	1245.02
6	N	29	49 0	E	30	38 10	2500	812.50	Straight	130.06	25.74	162.77	1.90	11.84	6.99	438.03	1238.03
7	N	29	39 0	E	30	51 50	2500	812.50	Straight	0.00	28.73	191.50	2.12	13.96	8.88	429.15	1229.15

Built-in restricted points:

Name	Latitude	Longitude	Distance
A	N 30 04 00	E 31 15 40	15 Km
B	N 31 11 00	E 29 57 00	15 Km
C	N 30 00 00	E 31 10 30	15 Km
D	N 30 47 00	E 30 59 55	15 Km
E	N 29 18 50	E 30 50 30	15 Km
F	N 29 28 00	E 30 36 30	15 Km
G	N 29 05 00	E 31 05 50	15 Km

Genral result

Total Distance 191.5 Km

Total Time 13.96 Mintue

Total Fuel Used 70.85 Kgs

Mission has been successfully calculated

Figure 8. The main report for case one

The report includes the following :

- Waypoint Number (user input), Waypoint 's Latitude and longitude (user input)
- True airspeed (AMPS output)
- Mode (user input and checked by AMPS)
- Heading (AMPS output)
- The distance between the current waypoint and previous one, (AMPS)
- Accumulated distance (AMPS)
- Time is taken from current waypoint and the previous one (AMPS)
- Accumulated time (AMPS)
- Fuel used (AMPS)
- Remaining fuel (AMPS)
- Changes in weight of the vehicle (AMPS)
- The built-in restricted points and their data.(AMPS)
- General result and conclusion

#### 4.1.5 *Comment*

Case one has been successfully calculated. Total distance 191.5 km, total time 13.96 minutes, total fuel used 68.77 kgs. No violation of the rules, limitations and restricted areas. All the modes are correct. AMPS allows adding a note or comment at the end of the report, such as what we write in the report “this report for case number one is to verify the system accuracy “. The user can add additional restricted areas from (restricted area) from the new mission in the mission calculation menu. And the new restricted points may be saved and called later. In the next cases adding newly restricted waypoints will be discussed. When the mission is planned correctly the report of errors is not available. If there are some errors, AMPS will suggest how to solve these errors and this situation will be clear in the next cases.

#### 4.2 **Case number two: Built-in restricted area**

In this case, we will highlight the restricted areas issue and how to avoid violating these areas.

##### 4.2.1 *Objective*

Check and verify AMPS dealing with restricted areas and how we can add new restricted points. Also get the reader to familiarize with the report of errors.

##### 4.2.2 *Inputs*

As in case number one the input data are entered through “Create new mission” interface from mission calculation menu figure 6, figure 9 shows the input data for the second case.

W.p. #	Latitude	Longitude	Mode	Latitude
0	N 29 33 45	E 30 53 42	Climb	10
1	N 29 40 00	E 30 47 15	Climb	-
2	N 29 49 00	E 30 38 00	Climb	-
3	N 29 48 00	E 30 25 00	Climb	-
4	N 29 35 00	E 30 15 00	Straight	5000
5	N 29 38 30	E 30 52 00	Straight	5000

Figure 9 . *The input data for case two*

##### 4.2.3 *Results (Outputs)*



After entering all required data, AMPS will check for errors, then messages explaining the violations in the restricted areas will be given. Two reports will be generated: The first one main report, figure 10, the second one will be the report of errors, figure 11.

#### 4.2.4 Comment

The main report will include aggregated results such as figure 10:

Total distance 147.91 km.

Total time 10.95 minutes.

Total used fuel 55.74 kgs

But “ Case failed ” is stated to alert the user to ask for the report of errors which includes the list of points calculated every one km which is a system parameter.

Report for mission Case_two.rpv													
Mission date : 3 / 12 / 2016													
Current date : 15 / 10 / 2016													
WP	Latitude	Longitude	Alt	TAS	Mode	Heading	Dist	A. dist	Time	A. time	F. used	R. rem	Wght
0	N 29 33 45	E 30 53 42	20	627.00	Climb	318.12	0.00	0.00	0.00	0.00	7.00	493.00	1293.00
1	N 29 40 0	E 30 47 15	1978	679.00	Climb	318.29	15.67	15.67	1.38	1.38	9.93	483.07	1283.07
2	N 29 49 0	E 30 38 0	3642	729.00	Climb	264.98	22.39	38.06	1.84	3.22	10.60	472.47	1272.47
3	N 29 48 0	E 30 25 0	4519	766.00	Climb	213.79	20.98	59.04	1.64	4.86	8.85	463.62	1263.62
4	N 29 35 0	E 30 15 0	5000	873.50	Straight	83.63	28.95	87.99	1.98	6.84	10.59	453.03	1253.03
5	N 29 38 30	E 30 52 0	5000	873.50	Straight	261.78	59.92	147.91	4.11	10.95	8.77	444.26	1244.26

Built-in restricted points:			
Name	Latitude	Longitude	Distance
A	N 30 04 00	E 31 15 40	15 Km
B	N 31 11 00	E 29 57 00	15 Km
C	N 30 00 00	E 31 10 30	15 Km
D	N 30 47 00	E 30 59 55	15 Km
E	N 29 18 50	E 30 50 30	15 Km
F	N 29 28 00	E 30 36 30	15 Km
G	N 29 05 00	E 31 05 50	15 Km

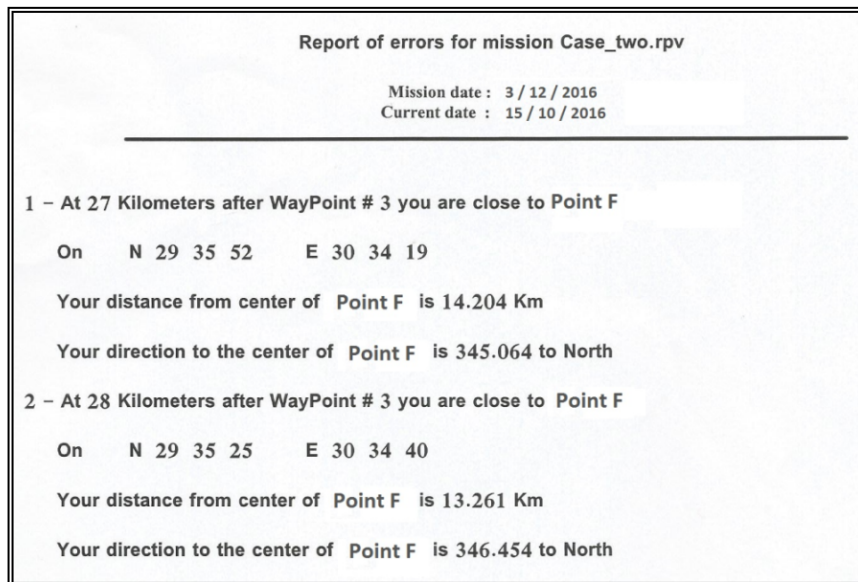
  

Genral result	
Total Distance	147.91 Km
Total Time	10.95 Mintue
Total Fuel Used	55.74 Kgs

Mission failed	
Ask for report of errors	
Errors found 2	

Figure 10. The main report for case two

Figure 11. *The report of errors for case two*

#### 4.3 Case Three: UAV emergency situations

In this case, we will show how AMPS is dealing with the violation of the limitation of the UAV performance curvatures.

##### 4.3.1 Objective

Check and verify AMPS dealing with violation of diving angle of the vehicle (It should not exceed 45 degrees).

##### 4.3.2 Inputs

As in case number one the input data are entered through “Create new mission” interface from mission calculation menu figure 6, figure 12 shows the input data for case number four.

W.p. #	Latitude	Longitude	Mode	Latitude
0	N 29 33 45	E 30 53 45	Climb	10
1	N 29 41 30	E 30 45 50	Climb	-
2	N 29 49 00	E 30 38 10	Climb	-
3	N 30 01 45	E 30 25 00	Climb	-
4	N 30 09 00	E 30 39 00	Dive	8000
5	N 30 10 00	E 30 39 00	Dive	1000

Figure 12. *shows the inputs data for case three*

##### 4.3.3 Result (Outputs)

After entering all required data AMPS will check for errors, then a message, including Dive angle between waypoint 4 and waypoint 5 is (63.52 degree) which is greater than 45 degrees (the limited angle for the vehicle) and two reports will be available, the first one Main report figure 13, the second will be the report of errors figure 14.

##### 4.3.4 Comment

The main report will include:

Total distance            101.53 km  
 Total time                 7.34 minutes  
 Total used fuel            500 kgs

But “ Case failed ” is stated to alert the user to ask for a report of errors which include the error of dive angle violation between waypoint 4 and 5.

Report for mission Case_3.rpv														
Mission date : 30 / 11 / 2016 Current date : 1 / 2 / 2017														
WP	Latitude	Longitude	Alt	TAS	Mode	Heading	Dist	A_dist	Time	A_time	F_usd	R_rem	Wght	
0	N 29 33 45	E 30 53 45	10	626.00	Climb	318.42	0.00	0.00	0.00	0.00	7.00	493.00	1293.00	
1	N 29 41 30	E 30 45 50	2430	809.00	Climb	318.44	19.34	19.34	1.43	1.43	11.10	481.90	1281.90	
2	N 29 49 0	E 30 38 10	3771	852.00	Climb	318.22	18.61	37.95	1.31	2.74	9.09	472.81	1272.81	
3	N 30 1 45	E 30 25 0	5526	799.00	Climb	59.04	31.73	69.68	2.38	5.12	8.64	464.17	1264.17	
4	N 30 9 0	E 30 39 0	6400	887.00	Dive	359.99	26.15	95.83	1.76	6.88	7.04	457.13	1257.13	
5	N 30 10 0	E 30 39 0	1000	730.50	Climb	261.78	5.70	101.53	0.46	7.34	2.93	454.20	1254.20	

Built-in restricted points:			
Name	Latitude	Longitude	Distance
A	N 30 04 00	E 31 15 40	15 Km
B	N 31 11 00	E 29 57 00	15 Km
C	N 30 00 00	E 31 10 30	15 Km
D	N 30 47 00	E 30 59 55	15 Km
E	N 29 18 50	E 30 50 30	15 Km
F	N 29 28 00	E 30 36 30	15 Km
G	N 29 05 00	E 31 05 50	15 Km

Genral result	
Total Distance	101.53 Km
Total Time	7.34 Mintue
Total Fuel Used	45.8 Kgs

Mission failed	
Ask for report of errors	
Errors found	1

Figure 13. The main report for case three

Report of errors for mission Case_three.rpv	
Mission date : 30 / 11 / 2016 Current date : 1 / 2 / 2017	
1 - Dive angle between WP # 4 and WP # 5 = 72 55 > 45 .	
Your direction to the center of karoon lake is 268.825 to North	

Figure 14. The report of errors for case three

## 5. Conclusion and future work

### 5.1 Conclusion

Three case studies are handled in this paper to the proposed AMPS (Automated Mission Planning System) which includes three different areas:

- \* **Mission calculation area** which is involved in mission data processing to check and ensure the correction of the calculated data.
- \* **Pre-Mission calculation area** which is involved in the preparation of the mission planning stage. This area supports the planner with different required tools to provide him with quick help in the related subjects.
- \* **Emergency area** which is involved in the emergency cases of the UAV and how to identify and differentiate between the different cases also how to deal with these cases to avoid some risks that might be caused by them.

### 5.2 Future works

- \* Make integration between AMPS and GPS activity on the internet (Almanac) to get a more accurate calculation.
- \* Make integration between AMPS and metrology broadcast to make correct and prompt information about wind parameters which are involved in the mission calculations.
- \* Design a simulation system which imitates the real one and this simulator could be practiced in training proposes to save time and money.

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