ESA Contract No. 4000112602/14/NL/MH

ESA STUDY CONTRACT REPORT

No ESA Study Contract Report will be accepted unless this sheet is inserted at the beginning of each volume of the Report.

ESA Contract No:	SUBJECT:	CONTRACTOR:
4000112602/14/NL/MH/as	*Integrated Vehicle Health Management System*	*Meteolabor AG*
ESA CR( )No: iHMSD-ML_ESP	No. of Volumes:1 This is Volume No:1	CONTRACTOR'S REFERENCE: iHMSD-ML_ESP

ABSTRACT:

Executive Summary Report

This document describes all tasks untertaken as part of the iHMSD Phase 2 project.

- Time plan, milestones and deliverables
- Legal Issues
- Integration and test of HW and SW prior to the FAR
- Low-level Missions up to 1200 m AGL , June - September 2015 Esrange, Kiruna. Flight Missions up to 32 km AGL with near Supersonic Speed

And it gives a conclusion over the work done.

Names of authors: Rolf Kessler, Meteolabor AG

NAME OF ESA STUDY MANAGER:	ESA BUDGET HEADING:
Dr Guillermo Ortega (TEC-ECN) DIV: Control Systems Division DIRECTORATE: Technical Directorate	GSTP 4.1

Integrated Vehicle Health Management System Demonstrator

iHMSD

Title	Executive Summary Report
Reference	iHMSD-ML-ESP
Issue	1 **Revision** 0
Date	23.11.2015
Confidentiality	☒ Unrestricted ☐ Restricted ☐ Confidential
Contract	ESTEC Contract **4000112602**
Technical Officer	Daniele Gherardi, ESA TEC-ECN
Approval	

Preparation	Release
Rolf Kessler, Meteolabor ag	Rolf Kessler, Project Manager, meteolabor ag

Document Change Record			
Issue	Rev.	Date	Modified pages and description/reason
1	0	23.11.2015	First issue

This document is valid without signature

Table of Contents

1 Work Performed in Phase 2

1.1 Time plan, Milestones and Deliverables

The project plan is shown below.

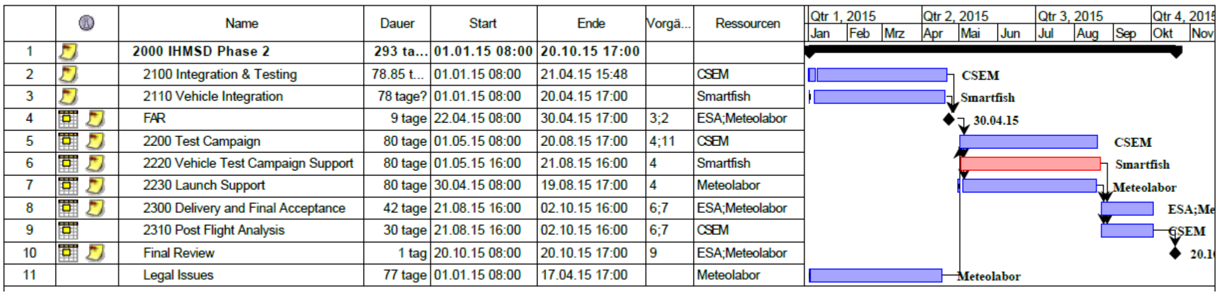

Figure 1: Gantt chart of the project Phase 2

Table 1: Milestones Phase 2

Milestone	Acronym	Date
Kick-off Meeting	KOM	2014-12-16
Flight Acceptance Review	FAR	2015-06-11
Final Review	FR	2015-11-27

Table 2: List of Document Deliverables.

Document name	ID	SoW ID	Milestone	Delivered
Mission Definition Re-entry vehicles HMS Literature Survey Preliminary Mission Definition Preliminary Development & Test plan for task 2	D1101	 D1.1 D1.2 D1.3	MDR	Yes
Mission Scenario Definition	D1201	D2.1	PDR	Yes
Mission Analysis Document	D1202	N/A	PDR	Yes
Vehicle Preliminary Design Preliminary Design of the test vehicle Vehicle development plan	D1221	 D2.2 D2.3	PDR	Yes
HMS Preliminary Design	D1211	D2.4	PDR	Yes
HMS Design & Simulation Results HMS Detailed Design HMS Simulation Results	D1301	 D3.1 D3.5	DR	Yes
Vehicle Detailed Design Vehicle AIT Plan	D1321	D3.2 D.4.5	CDR	Yes

Document name	ID	SoW ID	Milestone	Delivered
FES Specification & Design FES Specification Document FES Detailed Design	D1311	 D3.3 D3.4	CDR	Yes
Final Report Phase 1 Contractual Phase 2 Development & Test Plan	D1302	D3.6 D3.7	CDR	Yes
Real-Time Test Bed Specification & Design Real Time Test Bed Specification Document Real Time Test Bed detailed design	D2101	 D4.1 D4.2	FAR	Yes
HMS Real-Time Simulation Test Plan and Results HMS real time test plan HMS real time simulation results	D2102	 D4.3 D4.4	FAR	Yes
Flight Acceptance Tests Report	D2103	D4.6	FAR	Yes
Flight Test Results	D2201	D5.1	FR	Yes
Final Report Activity synthesis, review and recommendations	D2301	D6.1	FR	Yes
Technical Data Package (all deliverable documents including updates to) Revised version of the complete data package	D1301 D1311 D1321 D2102	 D6.3	FR	Yes
Summary Report	D2302	D6.4	FR	Yes
Abstract	D2303	D6.2	FR	Yes

1.1 Legal Issues

Several flight tests could be performed legally in Switzerland. Flights beyond line of sight require authorization of the Swiss Federal Office of Civil Aviation (FOCA).

The team met with FOCA officials on 2013-01-25. All technical design questions have been clarified and accepted by FOCA. The iHMSD vehicle design has been cleared for flights. FOCA requests that mid-air–collision risks are mitigated by flying by night and/or by coordinating daytime iHMSD missions with the national air-traffic–control agency SkyGuide.

The team held a joint meeting with SkyGuide and FOCA officials on 2013-01-31. After analyzing the possible ways of mitigating mid-air–collisions it was agreed that the best way to proceed with the fastest implementation time is to use military reserved airspace in coordination with the Swiss Air Force (SAF). FOCA, as administrator of the Swiss airspace has already requested that SAF collaborates with the iHMSD team. A meeting with SAF officials is being pursued in February 2013. Depending on the outcome of that meeting, it might be possible to perform the totality of the iHMSD flight tests in existing reserved airspace. Otherwise, it might be necessary to request from FOCA an additional reserved airspace for iHMSD activities below 4-km altitude. Processing this request may take a maximum of 3 months.

FOCA has signaled that flight authorization will be granted progressively matching the iHMSD test plan and as successful missions are reported. However, the reality showed, the FOCA not to be too cooperative after all.

Since 2012, it became much more difficult to get a flight permission for drones. Luckily, Meteolabor approached FOCA already in May 2014 on own financial risk, to get flight permission for the iHMSD project. As it turned out, this took much longer and was much more intense than planned and financed from ESA. It took us 362 days to get the first flight permission, up to 1000 m AGL at Kägiswil in a radius of 200 m, and this only in the morning from 05:00 – 07:00 local time. We had to write a 106 pages so called Gallo document and identify and describe several flight barriers and describe every possible error scenario with event sequence diagrams.

We were informed, that the procedure towards a flight permission is basically the same, whether it is for a 1.2 kg heavy glider or a Boing 747. No discussion on that.

We received the first permission in late June 2015 with the restrictions mentioned above. Right after we received it, Meteolabor started negotiation with FOCA, to get permission with less restrictions. We applied for permission with a radius of 3km and up to 40 km AGL. CSEM had relations to the Swiss Air Force and used this successfully to get this permission by using the military airspace. We would have been able to use that airspace in times where the air force would not need it. But again, the FOCA did not allow it.

Finally we (Gabriel Gruener, Matthias Höchemer and Rolf Kessler) had a last meeting with FOCA in Bern on the 18. September 2015 after we completed successfully the low-level flight missions. This meeting was so loaded with emotions from both sides, that Gabriel Gruener walked away for a couple of minutes. Matthias told me, this has never happened before. Anyway, the result of this meeting was, the Consortium needs to hire a flight safety engineer to provide the necessary event sequence diagrams and fault trees for at least three months, with six months beeing more likely. This would have costed an additional 150’000 Euro at least. A no-go to us and ESA.

We finally managed to get an additional permission for flights up to 3 km AGL. However, this permission was of not much use too us, so we made use of our plan B scenario, Esrange – Kiruna.

1.2 Integration and Tests of Hardware and Software prior to the FAR

One propelled vehicle and three glider vehicles have been manufactured. All three gliders have undergone functional many on the ground. In addition, one glider vehicle was subjected to thermal tests.

Test	Pass/Fail	Comment
Functional Test	Pass	Servos, Visual Inspection, COG ak
Thermal Tests	Pass	We did three iterations on our cold chamber until we were satisfied with the results. The temperature was -40°C, the duration was3 hours per test with an airr pressure of 950. We improved several things during this test, including the hot-wire (used to release from the balloon) and the isolation and the power supply.
Hardware Test	Pass	A balloon flight was performed in 2012 and the result was, that the Xbee telecommands module needs an external pwer supply on the ground.

Test	Pass/Fail	Comment
Software Tests	Pass	All components of the SW are working properly. This includes: • Real-time kernel • Failsafe trigger • Attitude estimator • Attitude controller • Guidance estimator • Guidance controller • Path planner • Ground Station

Table 3: Tests before FAR

1.3 Low-level Missions up to 1200 m AGL , June - September 2015

Figure 1: The Smartfish

Instead of describing single missions we put here the last mission, which is also a good indicator of what we have achieved in this time. All these missions were flown in Kägiswil, a Swiss airport, in the early morning from 05:00 till 07:00 in the green circle below.

Figure 2: Flight path of the last flight performed in Kägiswil

Time	**06:30**
Max Altitude	1662m (1182m AGL)

Main achievements:

Perfect Hotwire release

Acceleration phase with nearly 90° (~88°)

Nearly no overshoot after level-off phase

Nice spiraling

Test Log HMS successfully activated in flight

Tasks for next missions:

Missions worked perfectly. All systems are working as expected.

For the next missions we need more airspace, this means we will fly in Kiruna.

Table 4: Results of the last low-level flight

1.3 Esrange, Kiruna. Flight Missions up to 32 km AGL with near Supersonic Speed

The Swedish Space corporation (SSC) owns and runs ESRANGE, located 45 km East of the town of Kiruna. From this facility SSC launches sounding rockets and high-altitude balloons for research in the areas of microgravity, astrophysics, astronomy and atmospheric studies. SSC has been offering suborbital launches to the scientific community for more than 40 years. The rocket impact area with a total area of 5,600 km² is located north of Esrange Space Center in the Swedish tundra region. In the whole area air traffic can be limited during rocket or balloon launches. Switzerland is supporting ESRANGE in paying part of the annual cost of the Range.

The decision to stop testing in Switzerland and to move to ESRANGE has been taken 5 weeks before actual campaign date, 3 weeks later we had the required permission, only short time remained to assemble the team, organize the campaign and send material to Sweden.

Due to budget ant time restrictions we had only a short time in Sweden, the goal was to do as many flights as possible to finish all the tests required, and to improve/adapt the vehicle (and parameters) during the campaign if required. A total of 12 flights were planned, knowing that weather or technical problems might force us to cancel some flights. The plan was to start at low altitude (where we finished with tests in Switzerland) and go step by step higher and fly faster, to reach finally over 30km and top speed of Mach 1.

Due to high wind speed in that season, it was clear that the balloon *launches* would be outside of the impact area, (close to Norwegian border). Landing where preferably at ESRANGE balloon pad, but we did not know exactly what is the distance that the vehicle can fly against the strong winds, and how much altitude would be used for acceleration phase and for flying back, therefore some landings where in the impact area, which also was our absolute limitation for using the vehicle in controlled mode. (balloon climbing to release altitude was allowed under radiosonde restrictions, i.e. also outside of the impact area).

The table below summarizes the Swedish missions and the results achieved.

Mission	**Wind speed** [km/h]	**Altitude** [km]	**Est. Max. Speed** [M]	**Comment**
iHMSD-151019-1430	13	1	0.125	Perfect test flight
iHMSD-151019-1630	16	2	0.142	Perfect test flight
iHMSD-151020-1100	-	23	-	No separation (SW)
iHMSD-151021-1400	67	8	0.237	Strong wind
iHMSD-151022-1126	81	14		Perfect test flight, too short acceleration phase
iHMSD-151022-1331	73	14		Uncontrollable flight due to loose battery pack

Mission	**Wind speed** [km/h]	**Altitude** [km]	**Est. Max. Speed** [M]	**Comment**
iHMSD-151023-1000	79	32		No separation (cable broken). Wind equivalent: hurricane category 2
iHMSD-151024-1000	98	32	0.800	Wind equivalent: hurricane category 4
iHMSD-151024-1230	98	31	0.870	Wind equivalent: hurricane category 4

Table 5: Results of the flight missions in Kiruna

Considering that the glider was designed to fly in winds below 20 km/h, it can be said that the missions were a huge success, given the hurricane-like winds experienced. Still, these strong winds provoked a variety of failures with wide-ranging consequences for the results and the project's finances. Precious time in Kiruna was lost fixing/improving the vehicles, repeating failed missions, and rescuing the vehicles in the Swedish tundra with expensive helicopter flights.

A maximum release altitude of 32 km and a maximum speed of Mach 0.87 were achieved.

Figure 2: Impressions from the flights

2 Conclusion

During the iHMSD flight tests a total of 31 glider missions were flown:

- 9 copter missions in Switzerland
- 13 balloon missions in Switzerland
- 9 balloon missions in Sweden

In addition, about 50 propelled flights were performed. This RC propelled missions allowed to develop and test a variety of functions and features much faster than with a glider. Also, the usage of a copter to tog the glider allowed saving time and effort on balloon missions.

The team is profoundly convinced that the time and effort spent developing a simulation and using this simulation to perform a Monte Carlo analysis of the missions during phase 1 had little influence during phase 2 nor helped save time and effort during the flight tests. The simulation effort would have been much better invested in real flights.

The flight test results in the good Swiss weather of the summer 2015 were very encouraging. Unfortunately, legal issues with a flight permit from the Swiss authorities (FOCA) prevented the team from performing higher flights in Swiss territory. In particular, the initial encouragement and positive feedback from FOCA to apply for a flight permit ended up with outrageous requests to perform extremely complex and expensive failure analysis of every sub-component in the vehicle. If FOCA had communicated from the beginning that such complete FMEA would be requested, then the team would have limited all local efforts to low-altitude flights and concentrate on other locations for the high-altitude flights.

The high-altitude flights were performed at ESRANGE, Kiruna, Sweden. The point in time in October 2015 was quite adverse because of the reigning weather conditions, specifically strong winds. The team would have preferred to perform the tests in the summer of 2016 but the Agency decided to perform the tests immediately.

The iHMSD vehicle and missions were originally planned to be performed in winds below 20 km/h. During the Swedish missions, the 1-kg glider had to fly at times through winds of almost 200 km/h, equivalent to a hurricane of category 4. Nonetheless, several very successful missions could be flown, with the iHMSD vehicle reaching maximum speeds of almost Mach 0.9 and gathering hours of flight data and video footage.

The strong autumnal winds in north Sweden created a variety of originally unexpected problems and failures. These included broken hotwire cables, landings away from the goal position requiring expensive and time-consuming helicopter rescues and damaged vehicles. In order to cope with the extreme situation, the team struggled passionately to improve the original, good working system on site. This situation was time consuming, exhausting and risky. Due to all these issues, the final iHMSD test flights reached a maximum altitude and speed just short of the original goal.