D3.1 Flight Test Programme
Flight Test Phase #1

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Lead Beneficiary for this deliverable:	ONERA
Author(s): C. Thémiot (ONERA), J. Bartasevicius (TUM), B. Vanek (SZTAKI)	
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Project coordinator name and organisation: Bálint Vanek, SZTAKI

Tel. and email: +36 1 279 6113 vanek@sztaki.hu

Project website: flipased.eu

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PU	Public	**X**

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Glossary

BP	Back-up Pilot
CG	Centre of Gravity
DLR-SR	Institute of System Dynamics and Control (SR), DLR
ECU	Engine Control Unit
EDL	Engineering Data Link
EDMO	Special Airport Oberpfaffenhofen
FBG	Fibre Bragg Grating sensor
FLEXOP	Flutter Free Flight Envelope Expansion for Economical Performance Improvement
FM	Flight Manual
FTC	Flight Test Card
FTE	Flight Test Engineer
FTM	Flight Test Manager
FTO	Flight Test Operator
GCS	Ground Control Station
GPS	Global Positioning System
LiPo	Lithium polymer battery
MAV Link	Micro Air Vehicle Link
ONERA	Office National d'Etudes et de Recherches Aérospatiales (The French Aerospace Lab)
PIC	Pilot-in-Command
RWY	Runway
SZTAKI	Institute for Computer Science and Control
TOW	Take-off Weight
TUD	Technical Univerity of Delft
TUM	Technical University of Munich
UAV	Unmanned aerial vehicle

Table of Contents

1 Executive Summary

Targeting at two flight test campaigns with the existing FLEXOP demonstrator aircraft (Baseline) the aircraft needs to be prepared, ground tested and cleared for the individual test performed. This might go hand in hand with exchange of the wingsets under investigation leading to slight adaptations in the aircraft's center of gravity, weight and balance sheet and minor adjustments in the sensor and data acquisition system.

A detailed flight test programme is established in this document, defining the test objectives, means of compliance, requirements on specific test procedures to be followed. The Flight test programme also specifies abnormal behaviour measures and quality gates.

ONERA compiled this deliverable based mainly on data provided by TUM and previous experience from FLEXOP project.

This document describes the programme and operations of test flights for evaluating the performance of the FLiPASED aircraft. It also contains a table of the purposed test sequence with an overview of the main test points and conditions. This document does not give full details of each test points. These details can be found in the individual Flight Test Cards.

2 Planning and Documentation of Flight Tests

In this section, the concept and procedure of planning is described. In addition, overview of how the documentation of Flight Testing Operations will be done is included.

2.1 Flight Test Planning

Multiple meetings were held within the project partners during which Flight Testing was discussed. FLEXOP flight tests feedback was also taken into account. Requirements of the partners were compiled from which the actual Test Points were derived. The test points are summarized in Table 1.

The aircraft is equipped with interchangeable wings: -0 is the rigid wing, -1 is the flutter wing, and the new set of wing to be developed within FLiPASED is denoted -3 (the legacy aeroelastically tailored wing developed within FLEXOP is denoted -2). Since every flight involves significant risk, flight tests will be resumed with the -0 wings, which were already flight proven. The first 15 flights are devoted to establish the baseline and test some of the new equipment as discussed below. Flights 16-22, during the second year of flight testing, are devoted to flight testing active aeroservoelastic control solutions, which are the fundamental building block of the MDO process within the project. The final outcome of the project is the newly built wing, using advanced ASE MDO principles where structures and active control work hand in hand will be tested in the third year of the project within flights 23-26.

Table 1. Test Points for -0, -1 and -3 wings.

No.	Wing	Title	General
1	0.2	Taxi Test 1	Assessment of ground handling qualities.
2	0.2	Maiden Flight 1	Assessment of In-Flight Behaviour of Systems and Handling Qualities when flown by external pilot. Manual flight control only.
3	0.2	Maiden Flight 2	Public Maiden Flight
4	0.2	Air-Data Probe Calibration 1	Airspeed and altitude sensor calibration.
5	0.2	Flight Mechanics Test 1	Flight mechanics model identification. Doublets and step inputs on roll/pitch/yaw.
6	0.2	System Test 1	Engine model identification.
7	0.2	System Test 2	Airbrake model identification. Fly manoeuvers required to calibrate the airbrake model (low negative pitch manoeuvres with extended airbrakes)
8	0.2	Autopilot Test 1	Assessment of autopilot functionality and autonomous flight. Autopilot inner loop and course angle hold tests. Mode switching, altitude hold, IAS hold, WPS tracking.
9	0.2	Autopilot Test 2	Assessment of autopilot functionality and autonomous flight. WPS tracking including speed and altitude changes in between.
10	0.2	Autopilot Test 3	Check if the autopilot can hold a steady load factor (n_z) during turn. Check if the autopilot can follow the horse track closely.
11	0.2	Envelope Expansion 1	Turns with increasing bank angle (increasing load factor)
13	0.2	Systems Test 3	Testing of the direct drive. Perform full direct drive frequency sweep to identify its' influence on flight dynamics and aeroelastic modes.
14	0.2	Aeroelastic Test 1	Aeroelastic model identification. Sine sweeps on control surfaces. Multiple repetitions.
15	0.2	Flutter Test 1	Open loop flutter test. Flying one test leg, download data, verify that the speed can be increased further on, increase the speed for the next test leg. No flutter control.

16	1.1	Maiden Flight 3	Assessment of in-flight behaviour of systems and handling qualities when flown with wing -1.
17	1.1	Flight Mechanics Test 2	Flight mechanics model identification. Doublets/3211/sine sweep on roll/pitch/yaw inputs, multiple repetitions.
18	1.1	Aeroelastic Test 2	Aeroelastic model identification. Sine sweeps on control surfaces. Multiple repetitions.
19	1.1	Envelope Expansion 3	Turns with increasing bank angle (increasing load factor)
20	1.1	Systems Test 4	Testing of the direct drive. Perform full direct drive frequency sweep to identify its' influence on flight dynamics and aeroelastic modes.
21	1.1	Flutter Test 2	Open loop flutter test. Flying one test leg, download data, verify that the speed can be increased further on, increase the speed for the next test leg. With flutter controller on?
22	1.1	Flutter Test 3	Closed loop flutter test. Flying one test leg, download data, verify that the speed can be increased further on, increase the speed for the next test leg. Flutter controller on.
23	3	Maiden Flight 4	Assessment of in-flight behaviour of systems and handling qualities when flown with wing -3.
24	3	Flight Mechanics Test 3	Flight mechanics model identification. Doublets/3211/sine sweep on roll/pitch/yaw inputs, multiple repetitions.
25	3	Aeroelastic Test 3	Aeroelastic model identification. Sine sweeps on control surfaces. Multiple repetitions.
26	3	Envelope Expansion 3	Turns with increasing bank angle (increasing load factor). Drag measurements in every configuration.

The flight test programme was split into 4 phases as follows:

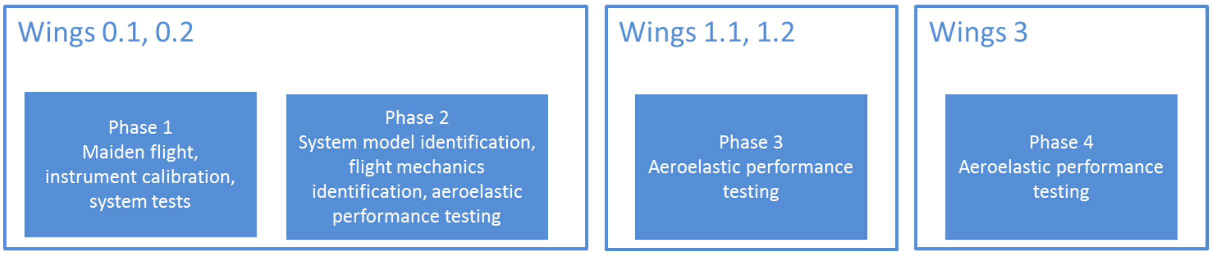

Figure 1. Phases of the Flight Test Campaign

For each phase of the flight test campaign, different limitations in terms of speed and altitude will be applicable. These conditions are mainly introduced via limiting the flight envelope. In addition, Phase 1 flights might be conducted without part of the measurement equipment inside the aircraft to reduce the risk of losing the hardware in an event of crash.

2.2 Documentation of procedures

Procedures, operations and related background information were compiled in five main documents for the FLEXOP project. They remain valid for FLiPASED flight tests and are described below.

2.2.1 UAV Flight Operations Manual

The UAV Flight Operations Manual describes the guidelines of how to safely and efficiently conduct test, research and training flights of unmanned vehicles within the Institute of Aircraft Design of the Technical University of Munich. Its main purposes are:

- to define the standard operations before, during and after a flight,
- to increase the safety and efficiency of a test or research flight and

- to be a method for making the transfer of knowledge from generation to generation easier.

This manual is intended to be a convenient source of the UAS procedures within TUM.

At the time of writing, version 0.8 of the document is available.

2.2.2 FLEXOP / FLiPASED Flight Manual

This Aircraft Flight Manual (FM) contains information required to safely operate the aircraft for research, test or training flights. It has the following chapters:

1. General
2. Limitations
3. Emergency Procedures
4. Normal Procedures
5. Performance
6. Weight and Balance
7. Airplane and Systems Descriptions
8. Airplane Handling, Service and Maintenance
9. Component List
10. Checklists

At the time of writing, version 0.4 of the document is available.

2.2.3 Flight Test Cards

The Flight Test Cards (FTC) incorporate the checklists used before and after flights and also the test points that are prepared for each flight. The checklists do not have major changes between the flights. The test points are created as required for the purposes of flight.

The FTCs are split into seven sections as described below. The FTCs should be followed in the exact order as described below.

All FTCs will be identical to FLEXOP FTCs except for FTC05 (Flight Test Cards) which will change for every flight test. A sample Flight Test Card describing a flight performed in July 2020 is shown in §5.1.

FTC01 – Flight Preparation [1]

FTC02 – Assembly [2]

FTC03 – Pre-Flight Briefing [3]

FTC04 – Systems Check and Engine Start-Up [4]

FTC05 – Flight Test [5]

FTC06 – Shutdown [6]

FTC07 – Post-Flight Briefing [7]

2.2.4 FLEXOP / FLiPASED Emergency Cases and Procedures [8]

This document describes the procedures in case of an emergency while operating the FLiPASED demonstrator. The document will outline the risk assessment done, the identified emergency cases and the derived emergency procedures that follow a failure.

The procedures are developed according to the following action plan:

1. Risk assessment
2. Identify the emergency cases

3. Identify a way to recognize them (if possible)
4. Write down an emergency procedure for the case
5. Group the emergency cases into what procedure is applied
6. Learn the emergency cases

At the time of writing, version 0.1 of the document is available.

Information mismatch inbetween the documents

Note that in case of mismatching information in between the various documents, the information should be prioritised in the following order:

1. FLEXOP / FLiPASED Test Cards
2. FLEXOP / FLiPASED Flight Test Programme
3. FLEXOP / FLiPASED Emergency Cases and Procedures
4. UAV Flight Operations Manual
5. FLEXOP / FLiPASED Flight Manual

2.3 Flight Test Operations

The flight test crew and their responsibilities are described below.

- Flight Test Manager (FTM)
    - Preparing the overall flight test programme, as well as writing flight-specific flight test plans. The FTM guides the pre-flight and post-flight briefings. During the flight, he announces the manoeuvres to be flown, communicates with the airport tower and makes in-flight adjustments on the flight plan.
- Flight Test Operator (FTO)
    - During the flight, the FTO follows the aircraft on the Mission Planner and is concerned with all the flight-critical parameters of the aircraft. With the help of the intercom he guides the pilot not to leave the allowed flight-box and advises the pilot on attitude, airspeed and altitude of the aircraft to conduct the maneuvers necessary for the testpoint.
- Flight Test Engineer (FTE)
    - During the flight, the FTE follows the Engineering Data Link window and is concerned with all parameters related to the health of the aircraft. He also is the backup for the FTO duties in case MAV Link connection is lost. Since he has more detailed data such as accelerations available, he will also record and give feedback on data during or after certain test points.
- Pilot-in-Command (PIC)
    - The PIC is the main pilot for the day. He fully controls the aircraft during the flight.
- Back-up Pilot (BP)
    - The BP takes over the control of the aircraft in case something goes wrong, either with the primary transmitter or with the PIC.

3 Conclusion

Flight tests have been planned and results of this work are shown in this deliverable. The test campaign for the first flight test phase is established to seamlessly provide the required data for model refinement and equipment testin. But this test plan is meant to be a living document what is iterated based on the new requirement and the obtained quality of data.

Besides the quality of data and possibilities for flight due to weather there are many more unknowns still in the plan; time planning is very difficult to anticipate due to COVID19 situation and unexpected ground controllability issues also delay the test campaign.

4 Bibliography

[1] FTC01 – Flight Preparation

[2] FTC02 – Assembly

[3] FTC03 – Pre-Flight Briefing

[4] FTC04 – Systems Check and Engine Start-Up

[5] FTC05 – Flight Test

[6] FTC06 – Shutdown

[7] FTC07 – Post-Flight Briefing

[8] FLEXOP Emergency Cases and Procedures, Munich, 2018

5 Annexes with additional information

5.1 Flight Test Card Example

Project	FLEXOP		
Location	Special Airport Oberpfaffenhofen, EDMO		
FTP	FLEXOP-FTP-02-00		
Test	1.9 Baseline Controller Check		
Test Objective	Outer loops check: horse race pattern.		
Ambient Information (**meteoblue.com**)			
RWY in use	04/22		
Aircraft Data			
ZFW, kg	57.8	TOW, kg	
Fuel, kg		CG, mm	606
Notes			

V_min = 25m/s, V_max = 53m/s
H_min = 150m, H_max = 300m

NOTE: Controller envelope is 26-70m/s, cruise flight state.

Date	26.07.2020	Engine Start/Stop Time	
Frequencies	119.55 (VDF), 122.1 O/R (VDF), 121.5 Emerg.Freq		
Test Crew (Call Sign), Signature			
Pilot-in-Command	(FLEXOP 1) ,		
Flight Test Operator	(OPERATOR) ,		
Flight Test Engineer	(ENGINEER) ,		
Back-up Pilot	(FLEXOP 2) ,		
Flight Test Manager	(MANAGER) ,		
Success:	Yes	No	Partial
Debriefing Notes			

1.	Engine **ON**	FLEXOP ONE, FLEXOP TWO	*		
2.	REPORT READY FOR TAKE-OFF	MANAGER			
3.	CHECK CONTROLS, FULL DEFLECTIONS	FLEXOP ONE			
4.	JETI WARNINGS **ON**	FLEXOP ONE			
5.	BRAKES **ON**	FLEXOP 1, FLEXOP 2, OPERATOR, ENGINEER			
6.	STANDBY TO ANNOUNCE TAKE-OFF AT 18m/s	OPERATOR			
7.	THROTTLE 100%, BRAKES **OFF** WHEN AIRCRAFT MOVES	FLEXOP 1			T-0
8.	ANNOUNCE **V1**	MANAGER			T+7
9.	FLIGHT STATE CRUISE, THROTTLE 70%, CLIMB 200	FLEXOP 1			At 30 AGL
10.	TRIM 38m/s	FLEXOP 1			

Horse Track Pattern 2					
11.	SELECT "HORSE RACE"	FTE	*		*FTE sets the controller mode via MAVLINK*
12.	TARGET AIRSPEED 38m/s, LENGTH 400m, CLOCKWISE	FTE			*FTE sets the MAVLINK parameters, sends the command.*
13.	CORRECT THE HEADING TOWARDS NORTH	FLEXOP 1			*Pilot adjusts the aircraft so that it would be aligned with the 040 heading*
14.	SWITCH AUTOPILOT 2	FLEXOP 1			*Around midpoint of the runway.* *Aircraft should start flying the horse track pattern. Keep for 2.5 loops.*
15.	TARGET AIRSPEED 38m/s, LENGTH 400m, COUNTER-CLOCKWISE	FTE			*When heading is 220, FTE sets the MAVLINK parameters, sends the command.* *Aircraft should continue flying the horse track, but in a counter-clockwise direction.*
16.	SWITCH AUTOPILOT 1	FLEXOP 1			
Horse Track Pattern 3					
17.	SELECT "HORSE RACE"	FTE	*		*FTE sets the controller mode via MAVLINK*

18.	TARGET AIRSPEED 38m/s, LENGTH 900m, CLOCKWISE	FTE			*FTE sets the MAVLINK parameters, sends the command.*
19.	CORRECT THE HEADING TOWARDS NORTH	FLEXOP 1			*Pilot adjusts the aircraft so that it would be aligned with the 040 heading*
20.	SWITCH AUTOPILOT 2	FLEXOP 1			*Around midpoint of the runway.* *Aircraft should start flying the horse track pattern. Keep for 1 loop.*
21.	TARGET AIRSPEED 34m/s	FTE			*FTE sets the MAVLINK parameters, sends the command.* *Aircraft should slow down, but continue the pattern*
22.	SWITCH AUTOPILOT 1	FLEXOP 1			
23.	TARGET AIRSPEED 34m/s, LENGTH 1400m, COUNTER-CLOCKWISE	FTE			*FTE sets the MAVLINK parameters, sends the command.*
24.	CORRECT THE HEADING TOWARDS NORTH, CLOCKWISE	FLEXOP 1			*Pilot adjusts the aircraft so that it would be aligned with the 040 heading, for clockwise pattern.*
25.	SWITCH AUTOPILOT 2	FLEXOP 1			*Around midpoint of the runway.* *Aircraft should start flying the horse track pattern.*

26.	TARGET AIRSPEED 38m/s, LENGTH 1400m, COUNTER-CLOCKWISE	FTE			*FTE sets the MAVLINK parameters, sends the command.*
27.	TARGET AIRSPEED 42m/s, LENGTH 1400m, COUNTER-CLOCKWISE	FTE			*FTE sets the MAVLINK parameters, sends the command.*
28.	SWITCH AUTOPILOT 1	FLEXOP 1			
Landing					
29.	PREPARE FOR LANDING	FLEXOP 1	*		
30.	GUIDE FOR LANDING, REPORT SPEED	OPERATOR			
31.	FLIGHT STATE LANDING	FLEXOP 1			
32.	CHECK CONTROLS, FULL DEFLECTIONS	FLEXOP ONE			
33.	ENGINE OFF	FLEXOP 1	*		
Plan B					
Flap Setting Trim Points					
34.	TRIM 38m/s	FLEXOP 1			
35.	FLAPS TAKEOFF	FLEXOP 1			

36.	DECEL-ACCEL	FLEXOP 1			Smoothly decelerate and then accelerate throughout the test leg
37.	FLAPS LANDING	FLEXOP 1			
38.	DECEL-ACCEL	FLEXOP 1			Smoothly decelerate and then accelerate throughout the test leg
39.	TRIM 42m/s	FLEXOP 1			
40.	FLAPS TAKEOFF	FLEXOP 1			
41.	DECEL-ACCEL	FLEXOP 1			Smoothly decelerate and then accelerate throughout the test leg
42.	FLAPS LANDING	FLEXOP 1			
43.	DECEL-ACCEL	FLEXOP 1			Smoothly decelerate and then accelerate throughout the test leg