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## **Stopping performance flight test on a flooded runway**

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### **Introduction**

The NLR activities described in this presentation are part of the EU-project Future Sky Safety (FSS). This project is an EU-funded transport research program in the field of European aviation safety. It has the overall objective to coordinate research and innovation actions targeting the highest levels of safety for European aviation. See <https://www.futuresky-safety.eu/>. One of the sub-projects within this EU-FSS project is “Project #3, Specific solutions for runway excursion accidents”. This project follows the recommendations of the European Action Plan for the Prevention of Runway Excursions (EAPPRE) that identifies area’s for which it is expected that additional research will reduce the number of accidents.

One of the identified solutions for runway excursions is the research into the “Impact of fluid contaminants of varying depth on aircraft stopping performance”. For this, NLR has carried out water-pond flight testing with the NLR/TUD Cessna Citation research aircraft to assess braking performance of modern aircraft and tyres on water covered runways. Airbus Military performed the same test using an A400M. Both tests took place using the water-pond facility of NLR. Aircraft operating on runways that are contaminated by standing water or slush (> 3 mm, up to the AFM limit) are significantly affected in take-off and landing performance. Most data available today is based on test carried out in the 60s and 70s of the last century. Improved aircraft braking systems and tires were only tested at small scale in recent years.



Figure 1 Aerial view of the airport of Twente and NLR/TUD research aircraft PH-LAB

### Test aircraft and water pond

The NLR research aircraft, a Cessna Citation II, and an Airbus A400 M were used during the flight test program. The Citation II is a twinjet aircraft of conventional aluminium construction and co-owned with Delft University of Technology. Originally designed for executive travel, the test aircraft (registration PH-LAB) has been extensively modified to serve as a versatile research and test platform. The basic crew consist of two pilots. Maximum take-off mass is 14.600 pounds, it has two Pratt & Whitney JT15D-4 turbofan engines and, as being relevant for the test, an anti-skid system.

In Europe only a small number of sites are suitable for tests at flooded runways. However their availability but did not fit our schedule (Cranfield UK, Istres France). The formal air force base Twente (EHTW), the Netherlands, turned out to be an option, but it lacked water pond facilities. NLR decided to construct a water pond at this airport. The pond was build using flexible re-enforced rubber strips as dikes. The longitudinal slope requires that several rubber cross dams had to be constructed to get reasonable consistent water levels in the water pond. These cross dams were placed every 7.7 m. The overall length of the water pond was 100 m. The nose wheel does not run in the water as only brake performance was assessed. The water pond is shown in Figure 2. The average water depth at the main wheel track was aimed at 15 mm. The runway 05/23 has a (cross section) camber of around 1.5 %, with some lower values near the centreline. The runway slope in longitudinal direction was 0.2 %. As a result in each section the water depth varied both in longitudinal and lateral direction. In the figure 2 the location of the main wheels, during pond passage, are indicated. A typical water depth distribution is given in figure 3.

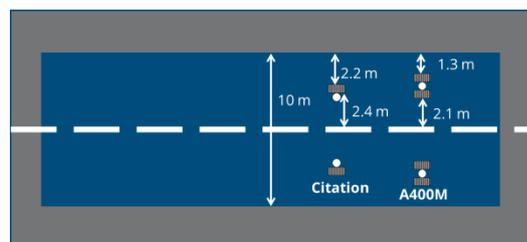


Figure 2 NLR water pond facilities at EHTW

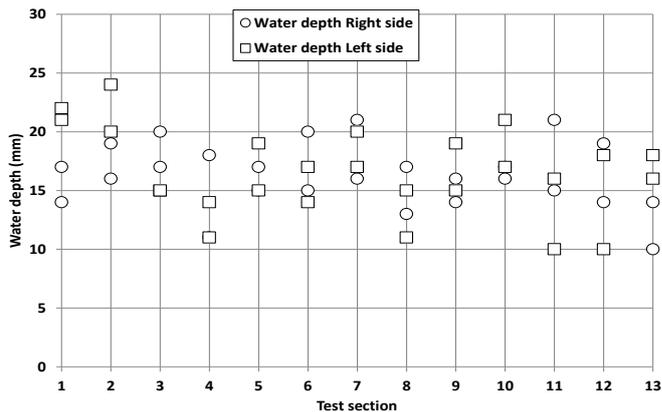
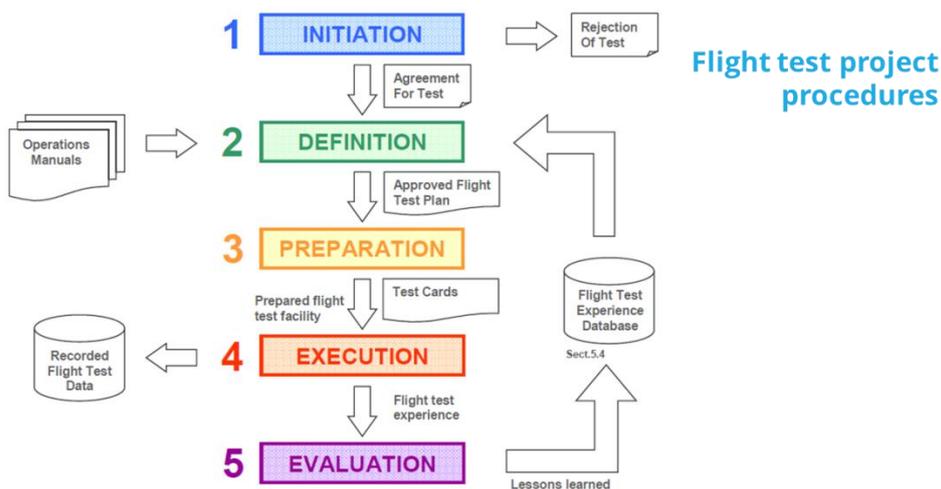


Figure 3 Typical water depth per test section

### Flight Test process

The NLR/TUD flight test organisation has the following flight test process in place.



In phase 1, the flight test process is initiated by the Request for Test (RFT). This is the handshake between the NLR project and the NLR/TUD flight test organisation. All known aspects of a requested flight test project should be identified and discussed, i.e. subjected to a preliminary assessment, including a preliminary risk assessment. Phase 1 is finalized by a Decision for Test.

During the preparation phase, the flight test effort was mostly directed to:

- How to deal with exceeding the FAR 25 - AFM limitation (max. 10 mm standing water)
- Solutions for the relatively steep runway slope/cross section
- Effects/safety issues that would arise due to brake application in the water pond
- Possible hydroplaning above 90 knots ground speed
- Convincing the Dutch Military of Defence that the test could be performed safely on their premises

Phase 2 contained the generation of a Flight Test Plan. In this plan, the test program is described and planned in detail. The flight test could be summarized as follows:

- Multiple runs through a water pond. All runs are accelerate - stop runs.
- Both main wheels run through the pond with standing water.
- The nose wheel runs on the dry/wet but not contaminated part of the runway. The middle part of the pond (where the nose wheel is running) is clear of standing water.
- A take-off configuration and idle power setting (when entering the pond) will be evaluated, with speeds ranging from 60 to approximately V1.
- No elevator input while running through the water pond.
- The runs are alternating brake and non-braked pond passages.

The Test plan includes a Flight Safety Assessment. Besides aircraft operation, the safety assessment included ground personnel and airport services related to the pond test. The following hazards were found:

1. (Multiple) engine failure
2. Nose wheel steering (NWS) failure
3. Flight control failure (primary and secondary)
4. Brake failure
5. Landing gear failure
6. Landing gear/ wheel well damage
7. a) Unintentional asymmetric pond entry, b) Unintentional asymmetric pond passage
8. Hydroplaning (a) symmetrical (b) asymmetrical
9. Variations in water depth
10. Collision with personnel and/or equipment on or besides the runway
11. Blown tire(s) or brake/wheel/tire fire due to excessive brake heating
12. Damage to aircraft due to rubber strips detaching from pond
13. Damage to engines due to excessive water ingestion
14. Shimmy in main landing gear when passing rubber strips

In the most critical scenarios the aircraft departed the runway surface at high speed due to directional control problems. The severity of such scenario was assessed to be 'Catastrophic' (hull loss and fatalities may be expected) in combination with the probability 'Remote' (unlikely, but possible to occur during project). The overall risk outcome of this FSA was MEDIUM risk.

The NLR test process calls for a Safety Audit when the outcome is MEDIUM or HIGH risk. One of the important outcomes of the Audit was the introduction of an additional go- no/go decision point during the day of execution. The objective of that step was to confirm the chosen probability. This review by the pilots and flight test leader was required before proceeding with higher speeds. Vital element was that the pilots were confident that the {probability} of hazard number 7b Unintentional asymmetric pond passage could be estimated {remote} for the high-speed runs. Otherwise the tests had to be stopped.

Phase 3, the preparation phase resulted in the aircraft, equipment and crew ready for the test flight and Test Cards generated.

## Flight Test Execution

The required results for this test campaign were:

- Acceleration data (longitudinal deceleration and lateral acceleration)
- Aircraft main wheel rotation data (derived from anti-skid system)
- Brake pressure in pilot side of the hydraulic brake system (low pressure part)

The runs were arranged in such a way that there was a build-up approach in water pond entry speeds. After a “pond clear” signal was received a static take-off was commenced from a pre-calculated starting point, this point varied with varying test speeds. The engines were set to idle at a fixed marked position before the water pond such that the aircraft entered the water pond near the target speed and with the engines in idle thrust. The SOP during test runs was such that the PF controlled the flight controls, thrust and brakes. The PM took (silently and) momentarily thrust control by closing the thrust levers prior to pond entry. PF applied brakes when the main gear passed the first pond strip. This could be identified visually and by the sound of the tire bumping over the strip.

### Results

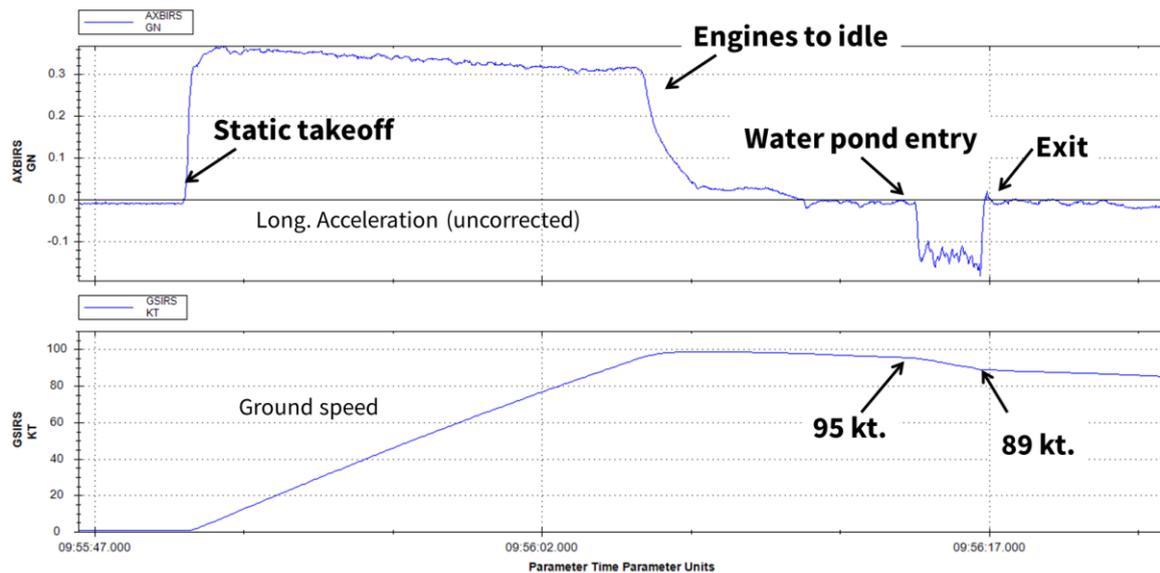


Figure 4: Longitudinal acceleration and ground speed time-history plot for a typical test run (ref. 1).

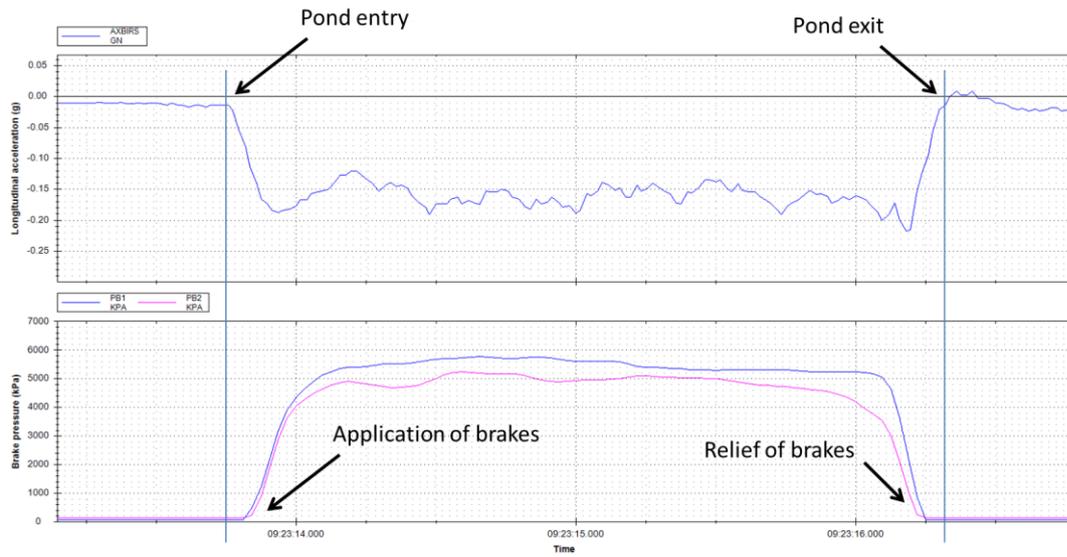


Figure 5: Time-history plot of longitudinal acceleration and brake pressure (ground speed between 85-78 kts.) (ref. 1).

## Selection of lessons learned



For a test pilot the most valuable part of the test is probably the part where lessons could be learned. Did our assessments fit reality? Were we trapped in test progress at some point?

The lessons learned during this project have been classified into the following flight test project management areas; requirements/scope, project schedule, budget, resources/ responsibilities, communication, flight test risks, execution.

ID	Area	Problem or Success description	Effect	Recommendation
1.	Scope/ Requirement	The requirement on the pond water depth changed during the project from 8/10 to 15 mm (exceeding AFM limit).	This generated continued airworthiness considerations.	Provide complete RFT from start of project. Include Part 21/ CAMO at this stage.
2.	Project schedule	Small pond pre-tested at Flevo polder location (including truck pond passage)	Gained experience with water pond operation and rubber strip behavior, minimizing risk of project pressure and delay.	Perform pre-test to reduce uncertainties during day of flight test.
3.	Flight Test risks	External expert was invited to participate in Safety Audit	Expert session provided valuable discussion/view	-
4.	Flight Test risks	Safety Mitigations were adequate	No occurrence/ incidents/accidents during	-

			flight test	
5.	Flight Test risks	The safety review during the day of execution	During our test it worked well. No controllability issues were found at lower speeds up to 70 knots.	
6.	Preparation	Was 10 kts increment in speed suitable?	-	60 kts as starting point was ok In aquaplaning regime consider speed increments of 5 kts for more data.
7.	Execution	Aircraft controllability turned out to be acceptable: 1) Nose wheel tracking (non-contaminated part of runway) contributed to this. 2) Aero dynamical control was effective (~VMCA 77, VMCG 62 KIAS) at higher speeds. 3) Rudder steering was required to maintain centerline tracking	Safe and efficient flight tests	-
8.	Execution	Combined max braking and steering requirement	Combined max braking and steering (pedals) proofed feasible	-
9.	Execution	Dry runs (no water) to gain experience and to validate model predictions of acceleration towards the thrust cut point.	Reduce uncertainty in flight test execution	-
10.	Execution	Incremental approach to build up pilot experience was adequate to be used in evaluation moment during the day of the flight test (review safety assessment)	Safe and efficient continuation of flight tests at higher speeds  However, when confidence in controllability would not have been so clear, the call to proceed could become under extreme 'day of execution' pressure.	Consider incremental approach in complex flight test/safety assessments.  BUT, safeguard for external pressure.
11.	Execution	Incremental Brake approach at high	It was the intention to focus	This approach was

		speeds.	at controllability and centerline tracking instead of maximum braking.	abandoned during the tests, as combined max braking and steering (pedals) proofed feasible
12.	Execution	Unexpected nose wheel lift at unbraked high speed run, halfway between starting point and pond entry.	Flight crew controlled aircraft to regain nose-wheel contact with runway. On successive run (high speed braked) adjusted elevator trim. Possible cause; lower weight than anticipated	Add hazard to project safety assessment
13.	Execution	Execution of flight test techniques with respect to data acquisition. E.g. Was maximum brake achieved? Was centerline tracking sufficient?	Execution was according test plan and all data was acquired successfully.	
14.	Execution	Contrary to planning, sidepiece markings on both main gear tires were omitted.	One could not visually (on video recordings) detect the tire speeds during water pond passages.	-

## Conclusions

The water pond stopping performance tests by NLR were successful. The flight test process was competent for preparing the flooded runway flight tests. The test was executed safely, according planning and the requested results were obtained.

## References

- Ref. 1 NLR's experience with flight testing on wet and flooded runways. Gerard van Es and Paul Koks, NLR 2017.