

Final Report

Project “Sklisikkerhet”

A report by Aircontact Services

Abstract

The overall objective of project “Sklisikkerhet” is to define minimum friction coefficients for stationary and moving helidecks in operation on the Norwegian continental shelf and provide guidance for implementation of a helideck friction verification regime. The report looks at actual friction requirements, laboratory and field test data, and provides relevant approximations, calculations, and comparisons. The report concludes with 10 recommendations.

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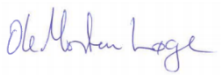
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Executive Summary

The regulation *BSL D 5-1 Forskrift om luftfart med helikopter – Bruk av offshore helikopterdekk § 16 - Sklisikkerhet* was introduced in 2019 but has not been implemented by the industry. This is mainly due to the industry not being able to see a practical solution for implementing the methods described in the CAA-N guidance material to the regulation. This report summarizes the findings of an industry consortium project mandated to define minimum friction coefficients for stationary and moving helidecks in operation on the Norwegian continental shelf and provide guidance for implementation of a helideck friction verification regime. The report comprises the following areas and topics:

- Minimum Required Helideck Friction
    - An approximation of a worst-case scenario for stationary helidecks with maximum allowable wind and estimated minimum helicopter weight was carried out. The minimum friction coefficient (μ) was calculated to 0.13.
    - The same approximation was carried out for moving helidecks. The minimum friction coefficient (μ) was calculated to 0.20.
- Helideck Test Data from Laboratory
    - Test data from two different helideck types, one with paint/antiskid grit and one with no paint and friction knobs, were processed. Average lower static and dynamic friction coefficients were calculated. This data is used when calculating scaling factors for harmonization.
- Measuring Static and Dynamic Friction in the Field
    - The feasibility of accurately measuring static and dynamic friction in the field is discussed. The conclusion is that accurately measuring static friction is near impossible and unpractical. Measuring dynamic friction is industry standard.
- Assessment of Portable Friction Testers and Harmonization
    - Two different commercially available friction testers were assessed. The resulting data were compared to the laboratory data and scaling factors were calculated.
    - For the painted helideck, both testers were reading higher values than in the laboratory data, one by an average factor of 1.22 and one by an average factor of 1.56. For the non-painted helideck, the factors were 1.56 and 1.39.
    - The conclusion is that harmonization by applying a predefined scaling factor to field measured values is an absolute requirement for a verification regime.
- The report concludes with the following recommendations:
    - The general minimum dynamic friction coefficient for stationary helidecks should be 0.6, the same as the current industry established value.

- The general minimum dynamic friction coefficient for moving helidecks should be 0.65, the same as the current industry established value.
- For helidecks commissioned prior to 01 January 2017 (legacy helidecks), a reduction in the minimum friction coefficient of 0.1 should be allowed, i.e. 0.5 for stationary helidecks and 0.55 moving helidecks.
- All helidecks must be monitored and/or maintained in service. The requirements shall be part of the helideck owner / operator approved maintenance program.
- Helidecks with wearable surfaces, i.e. paint and antiskid grit, shall be subject to a friction verification regime. Verification measurements should be carried out at predetermined intervals.
- Helidecks with non-wearable surfaces, i.e. unpainted and/or sand blasted with friction knobs or ridges, shall not require a friction verification regime provided that the friction coefficient have been determined by a full-scale laboratory test, i.e. “type certification”.
- For legacy helideck types, existing full-scale test reports from a cognizant laboratory may be used to determine the friction coefficient. If no full-scale test report exists for a particular helideck type, the helideck supplier or owner shall commission full-scale tests as required. Sample test pieces accurately representing each helideck type must be provided for the tests.
- For helideck friction verification, a portable friction tester employing the braked wheel method to determine the dynamic friction shall be used.
- Harmonization between the full-scale laboratory test and the field test (helideck friction verification) shall be an absolute requirement. The helideck supplier or owner shall be responsible for determining the scaling factor for each helideck type / field tester type combination.
- The document “Veiledning Til Forskrift Om Luftfart Med Helikopter – Bruk Av Offshore Helikopterdekk" must be updated to include acceptable means of compliance for the implementation of the above recommendations.

1. Introduction

1.1 History

After updating *BSL D 5-1 1 Forskrift om luftfart med helikopter – Bruk av offshore helikopterdekk* (FOR-2019-05-14-604), effective from 01.07.2019, a new approach to helideck friction named “Sklisikkerhet” was introduced. This new approach is regulated in §16 - Sklisikkerhet and is further described in the guidance material to the regulation. With the new approach, it is suggested that verification of friction should be done by measuring force in lieu of measuring friction coefficients. It is also suggested that a static friction reference should be used in lieu of a dynamic friction reference. The industry was at a loss as to how this should be interpreted and implemented.

CAA-N’s main concern is that friction coefficients in general do not refer to any known or predetermined values, approved or otherwise. This observation is correct, a friction coefficient is simply a dimensionless quantity indicating the ratio of two forces that act perpendicular and parallel to the interface between two contacting bodies. However, this report will show that the concern and the uncertainties can be mitigated by adding an additional step to the verification process, namely harmonization between laboratory and field measured data, providing an accurate relationship between two friction coefficients. Regarding the static and dynamic friction aspect, having limits and measurements referring to static friction is unpractical and difficult to do in the field. There is no known portable equipment commercially available.

As a result of the uncertainties and the long overdue implementation, a consortium og oil/energy companies decided to initiate a project to address the regulatory requirements.

1.2 Mandate for Project "Sklisikkerhet"

The mandate for the project was established on 09 June 2023. Aircontact Services AS was nominated to lead the project with support from Viatech AS, one of the leading companies in Norway for airport and road friction work and production of friction testers.

The following oil/energy companies are part of the consortium funding the project:

- Equinor
- AkerBP
- Conoco Phillips
- Vår Energi
- Repsol
- Okea

- Neptune energy

1.3 Project Organization

The project has been organized with a core team and an observation team.

Core team:

- Ole Morten Løge, ACS, Project Manager
- Morten Haugseng, ACS, Project Member
- Henning Hagen, ACS, Project Member / Quality Manager
- Halvard Haugland, Viatec AS, Project Member, Subject Matter Expert
- Arne Melheim, Equinor, Project Member, Nominated Industry Representative

Observation team:

- John Arild Gundersen, AkerBP
- Stian Løseth, Equinor
- Rune Meinich-Bache, Vår Energi AS
- Per Ivar Østensen, LTIL
- Per Helge Wilhelmsen, LTIL
- Bjørn Stein, PTIL
- Kjartan Nygaard, SDIR
- Sveinung Iversen, SDIR
- Øyvind Jonassen, Rederiforbundet
- Egil Bjelland, CHC HS
- Kjetil Hellesøy, Bristow Norway AS
- Tormod Tønnesen, Offshore Norge

The project has used Microsoft Teams for management of documentation, project plans, and meetings. Both the core and observation teams have had access to the project Teams site.

1.4 Overview Project Phases

1.4.1 Initial Phase

During the initial phase, the project collected and reviewed available existing information related to helideck friction, including projects completed in other countries, various regulations, as well as current practices. NLR – the Royal Netherlands Aerospace Centre was selected to provide full-scale laboratory testing and/or reports for helideck types as required by the project. The project established contact and had meeting activity with multiple entities throughout the process. Some of these are:

- CAA-N
- CAA-UK
- DNV- Det Norske Veritas, Norway
- NLR, Netherlands
- Marine Aluminum AS, Karmøy Norway
- Frictape, Finland
- Sarsys-ASFT, Sweden
- Bayards Up, Netherlands

1.4.2 Test and Assessment Phase.

The project carried out both laboratory and field tests on helideck samples to collect necessary data. NLR provided consolidated reports as well as complete data sets from full-scale tests. Data sets from previous full-scale tests carried out for other customers were also provided with approval from the data owners. Ramsys and Marine Aluminium provided field testers and assisted with verification test expertise. All collected data was assessed and reduced to min, max, and averages to be used in comparative analysis.

1.4.3 Final Phase

In the final phase, approximations and calculations using basic formulas were carried out to generate the results necessary to meet the mandated project objectives. This phase is fully documented in the report. The report concludes with 10 recommendations.

2. Minimum Required Helideck Friction

In order to assess the minimum friction factor required to prevent horizontal movement of a helicopter on the helideck, actual values for horizontal and vertical loads for a worst-case scenario have to be used. The horizontal load is represented by wind force and the vertical load is represented by helicopter weight. The following is an approximation for the Sikorsky S-92A helicopter.

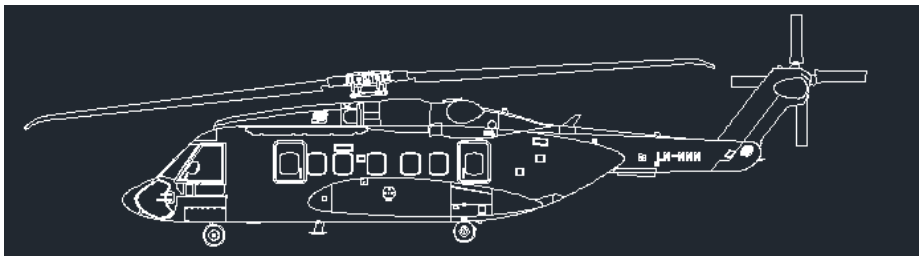
2.1 Parameter Definition

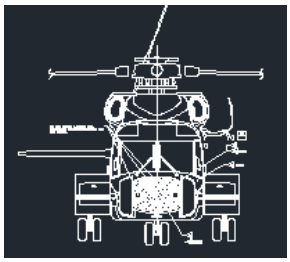
2.1.1 Helicopter Weight

The typical empty weight of the S-92 is 8200 kg. The estimated minimum fuel weight on deck is 800 kg. With no passengers, the minimum operational helicopter weight is estimated to be 9000 kg or 88260 N.

2.1.2 Projected Surface Area

Wind forces exerted are dependent on the projected surface area of the helicopter. Areas are calculated in Autocad for the helicopter positioned at 0 and 90 degrees relative to wind direction. An estimation is done for the helicopter at 45 degrees relative to wind direction. The projected area is considered to be a flat surface. Basic formulas are used in the approximation.





- Calculated projected area with relative wind at 0 degrees: 12.4 m2
- Calculated projected area with relative wind at 90 degrees: 41.9 m2
- Estimated projected area with relative wind at 45 degrees: 41.9 m2

2.1.3 Environmental and Technical Factors

The wind force calculation is done for a standard day at sea level (1013.25 hPa / 15^0 C), giving an air density of 1.225 kg/m3.

An assumption is made that the wind is always parallel to the horizon.

The wind speed used is 60 kts, the maximum limit for offshore helicopter operations. The maximum crosswind component of 35 kts for the S-92 is taken into account.

An assumption is made that the helicopter is stationary on the helideck with rotors running at flat pitch and parking brake set.

2.2 Wind Load Calculation

The basic equations used for this calculation:

Wind force $F = q\ Ae$ where q is the dynamic pressure and Ae is the effective area.

Dynamic pressure $q = 0.5\ \rho\ v^2$ where ρ is the air density and v is the wind speed.

Effective area $Ae = A\ \sin(angle)$ where A is the projected area, giving:

$$F = 0.5\ \rho\ v^2\ A\ \sin(angle)$$

Calculation 1 - Relative wind at 0 degrees. Wind speed at 60 kts (30.8 m/s)

$$F = 0.5\ x\ 1.225\ x\ 30.8^2\ x\ (12.4\ x\ \sin(90)) = 7205\ N\ (735\ kg)$$

Calculation 2 - Relative wind at 90 degrees. Wind speed at 35 kts (18 m/s)

$$F = 0.5\ x\ 1.225\ x\ 18^2\ x\ (41.9\ x\ \sin(90)) = 8315\ N\ (848\ kg)$$

Calculation 3 - Relative wind at 45 degrees. Wind speed at 49.5 kts (25.5 m/s)

$$F = 0.5\ x\ 1.225\ x\ 25.5^2\ x\ (41.9\ x\ \sin(45)) = 11800\ N\ (1204\ kg)$$

2.3 Required Friction Coefficient on Stationary Helidecks

The friction coefficient in this case is defined as

$\mu = f\ /\ N$ where f is the wind force and N is the helicopter weight.

For the worst-case scenario with the highest wind factor and the lowest helicopter weight as defined above, the minimum required friction coefficient is:

$$\mu = 11800\ N\ /\ 88260\ N = 0.133 \approx 0.13$$

2.4 Required Friction Coefficient on Moving Helidecks

On a moving helideck there are two additional forces, pitch/roll and heave, that will have effect on the required friction coefficient.

2.4.1 Pitch/Roll

The maximum allowable combined deck slant or incline for helicopter operations is 3 degrees. At this maximum, the resulting forces change:

$F(vertical) = mg\cos(angle)$ and $F(\text{parallel}) = mg\sin(angle)$.

$Fv = 88260\ N\ x\cos(3) = 88139\ N$ and $Fp = 88260\ N\ x\sin(3) = 4619$ N

Using the numbers from 2.3. above, adding to f and subtracting from N:

$\mu = 16419\ N\ /\ 88139\ N = 0.186 \approx 0.19$

2.4.2 Heave

The maximum allowable heave rate for helicopter operations is 1.3 m/s. Assuming a sinusoidal wave period of 10 seconds or frequency at 0.1 Hz, the maximum vertical acceleration can be calculated as the derivative of the maximum speed.

$\alpha_{max} = v_{max}\ 2\ \pi\ f$

$\alpha_{max} = 1.3\ x\ 2\ \pi\ x\ 0.1 = 0.816814 \approx 0.82$

Assuming a helicopter weight of 9000 kg, the normal force is reduced during downwards movement:

$F = 9000\ kg\ x\ (9.8 - 0.82) = 80820\ N$

Using the worst-case scenario for wind load, the minimum required friction coefficient is

$\mu = 11800\ N\ /\ 80820\ N = 0.146 \approx 0.15$

2.4.3 Compounded Effect

When combining the effects from maximum pitch/roll and heave, the minimum required friction coefficient is

$Fv = 80820\ N\ x\cos(3) = 80709\ N$ and $Fp = 80820\ N\ x\sin(3) = 4229$ N

Using the numbers from 2.3. above, adding to f and subtracting from N:

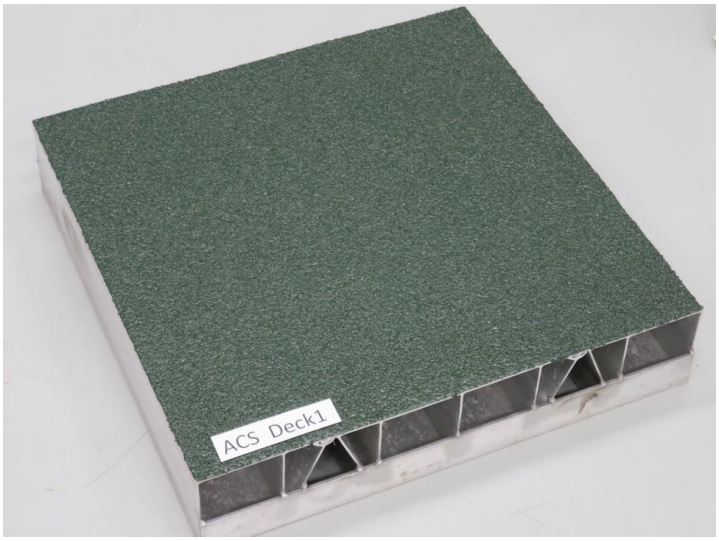
$\mu = 16029\ N\ /\ 80709\ N = 0.198 \approx 0.20$

3. Helideck Test Data

Over the years, a number of different helideck types have been tested in laboratory in order to find the inherent friction coefficient. These tests were carried out by Netherlands Aerospace Centre (NLR) typically for helideck manufactures / shipyards. Data from previous tests as well as data from new tests have been used in this assessment. The following helideck types, which represent two different friction mechanisms, have been selected for the assessment.

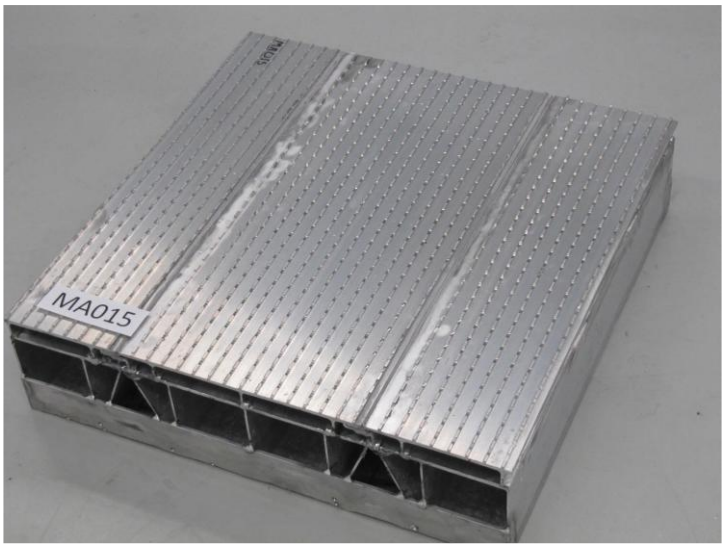
Marine Aluminium MA006, Flat surface without friction knobs

- Deck primed 200 µm + 600 µm added antiskid grit size 1,4-2,0mm in quantity 2kg/m2 + 75-100 µm topcoat.



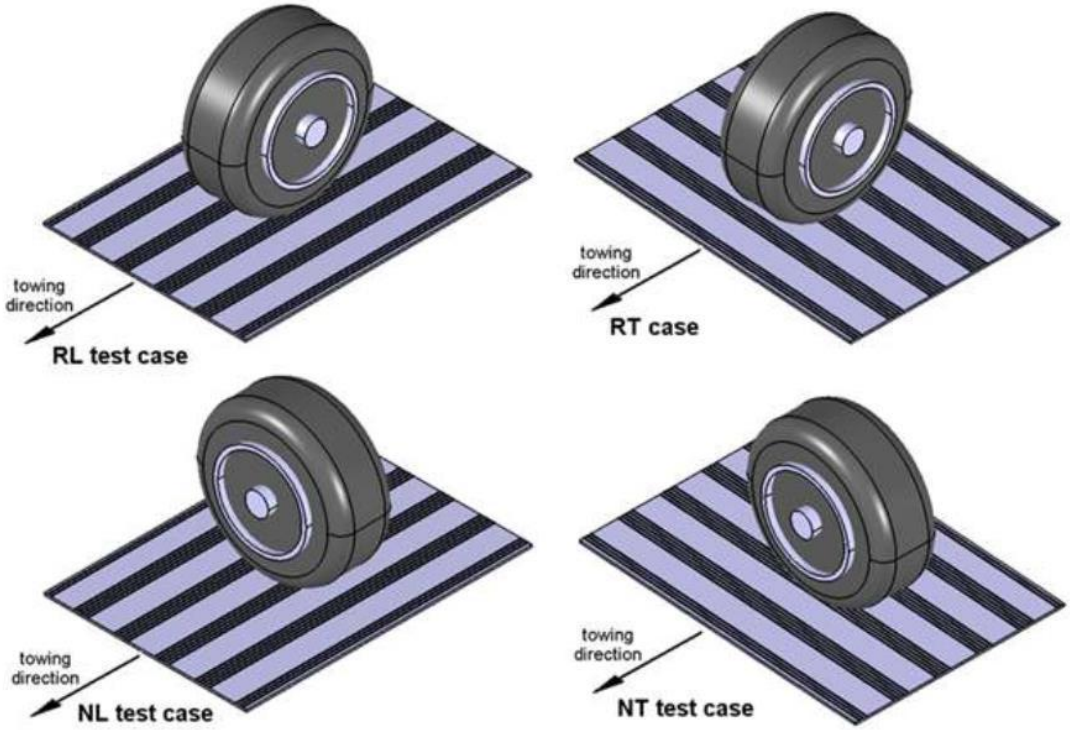
Marine Aluminium MA015, Friction Knobs - Safe Deck

- Untreaded. 10mm pattern friction knobs



3.1 Helideck Test Setup

Tests are carried out in a laboratory rig which is set up to represent the Sikorsky S-92, both in terms of forces (helicopter weight) and materials (wheel and tire). Refer to the NLR reports for details. A full test comprises 3 test runs in each direction as indicated in the figure:



3.2 Test Data

Datasets which are provided by NLR for complete tests of each sample helideck type comprises the following parameters relevant for this assessment:

Date/Time – Test timeline

Fx (f) – Horizontal towing forces

Fz (N) – Vertical wheel load

Mu (μ) = Fx/Fz (f / N)

Note: Fx, Fz, and Mu are designators used in NLR data files.

A dataset comprises data from 3 runs in 4 directions for a total of 12 runs. The number of acquisitions per run is approximately 9,000, giving a total of approximately 100,000 data points. As two datasets are used, the total of data points is approximately 200,000.

3.2.1 Data Reduction

The data for each test run is reduced from 9,000 lines to 1 line, extracting the Mu (μ) using functions for Average (AVG), Maximum (MAX), and Minimum (MIN). In addition, Standard Deviation (ρ) or SD is calculated.

Helideck 1 - Type MA006				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
000	0.72084	0.80681	0.69387	0.02572
001	0.71375	0.82830	0.69086	0.02570
002	0.71751	0.82489	0.69676	0.02208
003	0.71602	0.82051	0.69399	0.02154
004	0.71610	0.81091	0.69476	0.01843
005	0.72294	0.82223	0.69870	0.01973
006	0.75029	0.87711	0.71905	0.03138
007	0.72570	0.79855	0.69743	0.02070
008	0.72315	0.79189	0.69955	0.01904
009	0.71465	0.77139	0.69134	0.01467
010	0.70628	0.75515	0.68336	0.01337
011	0.70698	0.74556	0.68638	0.01164

Helideck 2 - Type MA015				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
000	0.57349	0.79180	0.55528	0.03800
001	0.61885	0.81532	0.59557	0.03547
002	0.62996	0.79228	0.60956	0.02881
003	0.79451	1.06088	0.75021	0.06860
004	0.74990	0.97364	0.72047	0.03315
005	0.71926	0.86706	0.69647	0.01771
006	0.61608	0.78090	0.32347	0.04190
007	0.61408	0.75420	0.34929	0.04480
008	0.59603	0.74008	0.38003	0.03375
009	0.80306	1.06407	0.61088	0.05873
010	0.74974	0.87571	0.59482	0.05316
011	0.72960	0.84099	0.56602	0.05459

Given that the type and volume of data for each run is equivalent, a simple average of all runs for AVG, MAX, and MIN can be calculated:

$$Average = a_1 + a_2 + \ldots + a_n \; / \; n$$

The average of SD is slightly different as more weight to values that are further from the mean provides a more accurate measure.

$$Average\ \rho = \sqrt{(s_1{}^2 + s_2{}^2 + \ldots + s_k{}^2)} \; / \; k$$

For the data above, the calculated summary values are:

Helideck 1 - Type MA006				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
	0.71952	0.87711	0.68336	0.02230

Helideck 2 - Type MA015				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
	0.68288	1.06407	0.32347	0.04570

The averaged data for Helideck 1 and Helideck 2 are further aggregated in the same manner as above, giving the final values:

Helideck 1 and Helideck 2				
Run #	AVG Mu	MAX Mu	MIN Mu	SD MIN Mu
MA006	0.71952	0.87711	0.68336	0.02230
MA015	0.68288	1.06407	0.32347	0.04570
AVG	0.70120	0.97059	0.50341	0.03596
SD MAX Mu		0.07974		

Note: The calculation of SD for MAX Mu (static friction) is different from SD for MIN Mu (dynamic friction) as there are no group averages. For SD MAX Mu, the highest single value for each run is used.

4. Sample Helideck Friction Assessment

Using the combined test data, we can extract both static and dynamic average friction coefficients.

- Static friction coefficient: 0.97059
- Dynamic friction coefficient: 0.70120

4.1 Calculated Lower Limit for Friction Coefficient

A statistical (mathematical) lower limit for the friction coefficients can be calculated from the test data. The lower limit is the mean of the data minus the variance in the data. Applying the empirical rule, with a confidence interval (CI) of 99,7%, almost all observed data will fall within three standard deviations. The lower limits are thus calculated:

$$\text{Lower limit} = \bar{x} - 3\delta$$

Calculation 1 – Lower limit – static friction

$$\text{Lower limit (static)} = 0.97059 - (3\ x\ 0.07974) = 0.73137 \approx 0.73 \approx 0.7$$

Calculation 2 – Lower limit – dynamic friction

$$\text{Lower limit (dynamic)} = 0.70120 - (3\ x\ 0.03596) = 0.59332 \approx 0.59 \approx 0.6$$

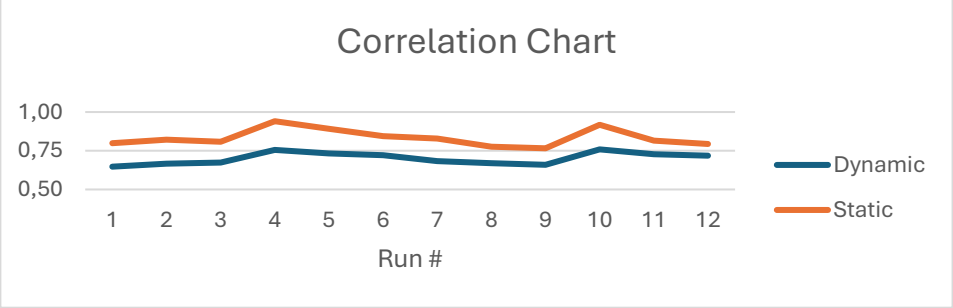
4.2 Suitability of Static and Dynamic Calculated Lower Limit

4.2.1 Data Variance

There is a significant difference in the standard deviation (or variance) between static and dynamic friction data. With SD at 0.07974 for static and 0.03596 for dynamic, the variability for static friction is more than 2 times that of dynamic friction. This could be an important factor, indicating that dynamic friction data may be better suited to calculate a lower limit.

4.2.2 Data Correlation

The data shows a good overall correlation between average static and dynamic friction values, as visually shown in the chart. This indicates that the difference between dynamic and static friction coefficients is close to constant for a given surface, i.e. the dynamic values can be used to represent the static values with high confidence.



5. Measuring Static and Dynamic Friction in the Field

In sections 3 and 4 above, we have assessed the friction data generated in the laboratory rig. The rig was configured to represent a real-world environment by applying about 2 ton downwards force on the single test wheel (emulating an S-92 at max weight - 12 tons / 6 wheels) and a wet deck. In the assessment we used data from two different deck types. Although not used in calculations, reports from testing of multiple other deck types were also reviewed. All test data appears to be similar and centered along the same amplitudes. If more data had been included in the assessment, the result would have been a slightly better correlation and smoothness. As a result, the approximation from two data sets is deemed adequate for the purpose.

The overall goal of this project is to implement a lower friction limit for helidecks and introduce a helideck friction verification regime. Whereas the test data can be used to set the friction limit, measuring and assessing data from actual helidecks in the field is a requirement for the friction verification regime. For this we must use a lightweight portable friction tester. The test articles are 1 by 4 meter samples of the deck types used in the laboratory tests, MA006 and MA015. Factors related to both static and dynamic friction testing are considered below.

5.1 Measuring Static Friction

Measuring static friction is a straightforward process where a horizontal force is exerted on a material (test piece) placed on top of another material until the test piece slips. The horizontal load is divided by the vertical load to find the static friction coefficient. However, it is far from this simple in our application where we aim to find the friction coefficient between an offshore helideck and a heavy helicopter. The following key factors must be considered.

- The friction in real conditions is generated by the rubber tire biting into the helideck anti-skid substrate (grit or friction knobs) as a result of the downwards force from the helicopter.
- With horizontal forces, the rubber tire deforms during the initial loading phase with a displacement up to 80 mm (from test data) before max static friction is reached and the tire starts to slip.
- The resulting max static friction value is only true and valid for the exact contact area between the helideck and the rubber tire at the time when the slip occurs.

Due to the factors above, it is considered difficult to simulate real-world conditions using a portable lightweight measuring apparatus. Such equipment for measuring static friction coefficients does not exist and would have to be developed from scratch.

5.1.1 Cost of Development and Purchase

In an endeavor to develop a lightweight portable friction tester which will be able to accurately measure static friction coefficients in this application, multiple initial studies, hardware and software prototyping, and extensive testing and evaluation would be required. Provided that such a project is successful, the equipment would have to be commercialized, as well as regulatory approved by relevant authorities. It is estimated that the cost could run into several millions of NOK. The risk of failure is considered to be high.

5.2 Measuring Dynamic Friction

Measuring dynamic friction is the standard method when checking friction coefficients in this type of application. This is the method used on roads and runways, as well as on offshore helidecks around the world. There are several lightweight portable friction testers commercially available. The two most likely candidates are:

- T2GO from Sarsys - ASFT
- Micro Grip Tester from Findlay Irvine

Both are lightweight, of robust construction, and have software to calculate and store measured data as required to provide a friction map of the area tested.

5.2.1 Cost of Purchase

The commercial price for a tester is approximately 250,000 NOK.

6. Assessment of Portable Friction Testers and Harmonization

Lightweight portable friction testers cannot completely replicate the conditions from laboratory tests where baseline friction coefficients for the different helideck types are measured. As a result, the friction measured in the field may be slightly different relative to the baseline. To compensate for this, a scaling factor must be applied to the field measured data. This is referred to as harmonization. Portable testers may behave slightly differently on different anti-skid substrates, i.e. grit, friction knobs, and friction ridges. Scaling factors may be defined for these three sub-categories. In some cases, it may be necessary to define scaling factors for individual helideck types, typically older configurations not fitting into any of the three sub-categories.

6.1 T2GO Friction Tester

Friction measurement trials were carried out with the T2GO friction tester on the two helideck types used as reference in this report, MA006 and MA015. The same assessment and data reduction methodology as applied to laboratory data in Section 3 above was applied.



6.1.1 Test Data Summary

Five test runs in wet conditions were carried out on each of the helideck types.

Helideck 1 - Type MA006				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
001	0.90550	1.00800	0.75400	0.06845
002	0.89364	1.13900	0.77000	0.09112
003	0.88768	1.06100	0.79500	0.06529
004	0.87354	1.00400	0.69300	0.06252
005	0.83243	1.01600	0.61500	0.11670

Helideck 2 - Type MA015				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
001	0.70446	0.87300	0.48000	0.10350
002	0.66075	0.79100	0.50400	0.07116
003	0.65564	0.80300	0.52500	0.07377
004	0.70557	0.83200	0.53300	0.07839
005	0.70318	0.86900	0.57000	0.07895

For the data above, the calculated summary values are:

Helideck 1 - Type MA006				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
	0.87856	1.13900	0.61500	0.08340

Helideck 2 - Type MA015				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
	0.68592	0.87300	0.48000	0.08197

6.1.2 Harmonization Scaling Factor

Using the average data from laboratory and portable tester results, the scaling factors for the T2GO are calculated:

$$\text{For MA006, } 0.71952 \,/\, 0.87856 = 0.81897 \approx 0.82$$

$$\text{For MA015, } 0.68288 \,/\, 0.68592 = 0.99556 \approx 1.00$$

6.2 Micro Grip Tester

Friction measurement trials were carried out with the Micro Grip Tester on the two helideck types used as reference in this report, MA006 and MA015. The same assessment and data reduction methodology as applied to laboratory data in Section 3 above was applied.



6.2.1 Test Data Summary

Five test runs in wet conditions were carried out on each of the helideck types.

Helideck 1 - Type MA006				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
001	1.11552	1.21000	1.02000	0.05320
002	1.11529	1.16000	1.04000	0.03603
003	1.12044	1.23000	0.96000	0.03979
004	1.13691	1.26000	1.02000	0.06830
005	1.14031	1.27000	1.02000	0.05262

Helideck 2 - Type MA015				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
001	001	1.11197	1.23000	1.03000
002	002	0.91838	0.99000	0.79000
003	003	0.92955	0.98000	0.82000
004	004	0.94456	1.00000	0.87000
005	005	0.86881	0.97000	0.75000

For the data above, the calculated summary values are:

Helideck 1 - Type MA006				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
	1.12570	1.27000	0.96000	0.05128

Helideck 2 - Type MA015				
Run #	AVG Mu	MAX Mu	MIN Mu	STDEV
	0.95465	1.23000	0.75000	0.04953

6.2.2 Harmonization Scaling Factor

Using the average data from laboratory and portable tester results, the scaling factors for the Micro Grip Tester are calculated:

$$\text{For MA006, } 0.71952 \,/\, 1.12570 = 0.63918 \approx 0.64$$

$$\text{For MA015, } 0.68288 \,/\, 0.95465 = 0.71532 \approx 0.72$$

7. Conclusions and Recommendation

7.1 Conclusions

The approximation data and calculations (Section 2) show that the minimum required friction coefficient to prevent slip on a stationary helideck is 0.13. For a moving helideck the minimum required friction coefficient to prevent slip is 0.20. Using the industry established lower friction limits of 0.6 and 0.65, the estimated safety factors are approximately 4.6 and 3 respectively. These safety factors are substantial and will cover and absorb any and all possible variables and uncertainties that may exist or occur. This should allow some leeway relative to legacy helidecks, which is defined as helidecks commissioned prior to the once-off full-scale laboratory test regime introduced by CAP 437 from 01 January 2017 (CAP 437 helideck requirements are referred to by all helideck suppliers, Norwegian or otherwise).

The laboratory test data (Section 3) comprises measurement runs in four towing directions, providing very good average friction results for both helideck types tested, MA006 (grit) and MA015 (friction knobs). Both deck types have friction coefficients near and centered around 0.7.

The helideck friction assessment (Section 4) shows that the calculated lower limit for dynamic friction is very close to and consistent with the industry established lower friction limit of 0.6. The data also shows a good and linear correlation between dynamic and static friction, meaning that one can be used to represent the other.

Section 5 discusses measurement of static versus dynamic friction in the field and stipulates that it is not feasible to use static friction in this application. Dynamic friction testing is easily done with existing equipment and this method is used on roads, airports, and helidecks world-wide.

The assessment of two different portable friction testers (Section 6) shows that both measures higher friction than the full-scale laboratory test, one of them substantially higher. Harmonization between laboratory and field measurements, i.e. scaling factor, is therefore the most important aspect of a new helideck friction verification regime.

7.2 Recommendations

Based on the findings, this project has the following recommendations.

1. The general minimum dynamic friction coefficient for stationary helidecks should be 0.6, the same as the current industry established value.
2. The general minimum dynamic friction coefficient for moving helidecks should be 0.65, the same as the current industry established value.
3. For helidecks commissioned prior to 01 January 2017 (legacy helidecks), a reduction in the minimum friction coefficient of 0.1 should be allowed, i.e. 0.5 for stationary helidecks and 0.55 moving helidecks. An alternative to fixed reduced values could be one-time assessment-based dispensations.
4. All helidecks must be monitored and/or maintained in service. The requirements shall be part of the helideck owner / operator approved maintenance program.
5. Helidecks with wearable surfaces, i.e. paint and antiskid grit, should be subject to recurring inspections. Inspection methods and intervals should be part of the helideck maintenance program.
6. Helidecks with non-wearable surfaces, i.e. unpainted and/or sand blasted with friction knobs or ridges, shall not require a friction verification regime provided that the friction coefficient have been determined by a full-scale laboratory test, i.e. “type certification”.
7. For legacy helideck types, existing full-scale test reports from a cognizant laboratory may be used to determine the friction coefficient. If no full-scale test report exists for a particular helideck type, the helideck supplier or owner shall commission full-scale tests as required. Sample test pieces accurately representing each helideck type must be provided for the tests.
8. For helideck friction verification, a portable friction tester employing the braked wheel method to determine the dynamic friction shall be used.
9. Harmonization between the full-scale laboratory test and the field test (helideck friction verification) shall be an absolute requirement. The helideck supplier or owner shall be responsible for determining the scaling factor for each helideck type / field tester type combination.
10. The document “Veiledning Til Forskrift Om Luftfart Med Helikopter – Bruk Av Offshore Helikopterdekk" must be updated to include acceptable means of compliance for the implementation of the above recommendations.

Appendix A – Reference Documentation

The following documents have been used as reference material in this project.

Document Title	Optional Info	Document Owner	Year of Issue
Friction tests on Aluminium Offshore Pte Ltd helideck with designation 353-B	NLR-CR-2017-241	Aluminium Offshore	2017
NLR Test set-up		CAA-UK	2012
Friction tests on Maritime Products AS helideck MP No.1	NLR-CR-2018-048	Maritime Products AS	2018
Oversikt over ulike typer dekk på Equinor Helidekk		Equinor	2023
Offshore Helideck Surfaces CAP 437 8th Ed v7b	CAP-437	CAA-UK	2017
Friction measurements of tyres on aluminium helicopter decks	NLR-CR-2011-146	CAA-UK	2012
Research into helideck friction measurement with nets	NLR-CR-2013-017	CAA-UK	2014
Evaluation of four helideck friction testers on behalf of the CAA	NLR-CR-2008-379	CAA-UK	2009
Friction Characteristics of helidecks on offshore fixed-manned installations	CAA Paper 98002	CAA-UK	1998
GripTester 0.65 criterion		CAA-N	1987
Policy – Helicopter deck – Surface Friction Characteristics – North Sea Operations		CAA-N	2015
Friction measurements on Marine Aluminium AS helicopter decks MA005, MA006 and MA007	NLR-CR-2017-167	Marine Aluminium	2017
Friction Measurements on two Marine Aluminium helidecks according to CAP437 edition 8	Decks MA012 and MA013	Marine Aluminium	2018
Friction Measurements on two Marine Aluminium helidecks according to CAP437 edition 8	Decks MA014 and MA015	Marine Aluminium	2018
Offshore Helideck surface friction trials	CIT-FI-85-063	Cranfield	1985
Comparison of results of NLR's test set up and the Findlay Irvine GripTester		Cranfield/NLR	2012
First results of tests on helideck with net	Internal Note	NLR	2013
BSL D 5-1 Bruk av offshore helikopterdekk	Including guidance material	CAA-N	2019
NLR-CR-2023-458	Friction tests on a helideck for ACS	Aircontact Services AS	2024

Appendix B – Attachments

Document Title / Name	Remarks	Document Owner	Year of Issue
Draft Guidance Material to BSL D 5-1 Forskrift om luftfart med helikopter – Bruk av offshore helikopterdekk § 16 - Sklisikkerhet	Draft Guidance Material (in Norwegian Language) attached	Aircontact Services AS	2024
Friction Tests on a Helideck for ACS NLR-CR-2023-458	Full NLT report attached	Aircontact Services AS	2024

Forslag til «veiledning til forskrift om luftfart med helikopter – bruk av offshore helikopterdekk - § 16 Sklisikkerhet»

Introduksjon
Krav til sklisikkerhet er innført for å sikre at helikopter og personell som benytter offshore helikopterdekk skal kunne utføre operasjoner og oppgaver på en tilstrekkelig sikker måte under alle godkjente operative værforhold. Tilstrekkelig sklisikkerhet oppnås ved at helikopterdekkets innebygde friksjonskoeffisient er høyere enn en pre-definert minimumsverdi.

Friksjonskoeffisient – Minimumsverdier
Minimumsverdier fremkommer fra test data og er oppgitt for forskjellige helikopterdekk som følger:

For helikopterdekk konstruert og produsert etter 01 januar 2017:
- For stasjonære helikopterdekk: 0.60
- For bevegelige helikopterdekk: 0.65

For helikopterdekk konstruert og produsert før 01 januar 2017
- For stasjonære helikopterdekk: 0.50
- For bevegelige helikopterdekk: 0.55

Note: Bakgrunnsdata for minimumsverdier finnes i rapport ACS-FR-2024-001.

Etablering av helikopterdekkets friksjonskoeffisient
For hvert enkelt helikopterdekk skal det etableres en friksjonskoeffisient (gjennomsnittsverdi fra laboratorietest). For helikopterdekk konstruert og produsert etter 01 januar 2017 er laboratorietest og etablering av friksjonskoeffisient en fast del av prosessen. For helikopterdekk konstruert og produsert før 01 januar 2017 kan eksisterende rapport fra laboratorietest brukes. For helikopterdekk hvor det ikke er utført laboratorietest er det helikopterdekkets eier eller operatørs ansvar å etablere friksjonskoeffisient. Prøvestykker som representerer den aktuelle helikopterdekk typen må fremskaffes og leveres laboratoriet.

Krav til verifisering av helikopterdekkets friksjon
For helikopterdekk med heldekkende slitebelegg, for eksempel maling eller anti-skli overflate, skal verifisering av friksjon med friksjonsmåler utføres hvert 3. år. For helikopterdekk uten slitebelegg, for eksempel umalt aluminium, friksjonsknotter, eller sandblåst overflate, er det ikke krav om verifisering med friksjonsmåler forutsatt at friksjonskoeffisient (gjennomsnittsverdi fra laboratorietest) har blitt etablert og ikke er lavere enn pre-definert minimumsverdi. I tillegg skal områder med merking ha minst like god friksjon som helikopterdekket for øvrig.

Verifisering helikopterdekkets friksjon og harmonisering av måleutstyr
Verifisering av helikopterdekkets friksjon gjennomføres ved bruk av portabel friksjonstester. Slike testere benytter samme måleprinsipp som i full-skala laboratorietester, men måleresultatet vil ikke nødvendigvis være likt. Harmonisering av måleresultat fra laboratoriet og portabel tester er derfor nødvendig. Dette gjøres ved å etablere en skaleringsfaktor for hver kombinasjon av helikopterdekk type og friksjonsmåler type. Det er helikopterdekkets eier eller operatørs ansvar å etablere skaleringsfaktor.

Vedlikeholdsrutiner
For alle helikopterdekk kreves det en grad av vedlikehold. Det er helikopterdekkets eier eller operatørs ansvar å definere, følge opp, og gjennomføre vedlikehold. Krav og rutiner, inkludert det som, omhandler sklisikkerhet, skal beskrives i helikopterdekkets eiers eller operatørs vedlikeholdsprogram. Vedlikeholdsprogrammet skal også, for hvert enkelt helikopterdekk, inneholde følgende minimum vedlikeholds relatert informasjon:

- Byggeår
- Typebetegnelse
- Friksjonskoeffisient (gjennomsnittsverdi fra laboratorietest)
- Verifikasjon, krav eller fritak
- Friksjonsmåler type / modell
- Skaleringsfaktor for friksjonsmåler

Note: Teksten over er tenkt å erstatte nåværende tekst i «veiledning til forskrift om luftfart med helikopter – bruk av offshore helikopterdekk - § 16 Sklisikkerhet», bortsett fra følgende eksisterende tekst som beholdes uforandret, bortsett fra en mindre forandring:

Tilstrekkelig sklisikring personell
Personellet som benytter helikopterdekket er enten personell om bord i helikopteret utstyrt med overlevingsdrakter eller ansatt på installasjonen med fottøy tilpasset bruksområdet. Ansatte på installasjonen, eller andre som er under kontroll av ansatte på installasjonen, forventes å være utstyrt med fottøy som er tilpasset bruksområdet.

Overleveringsdrakter testes og godkjennes iht. IMO/Solas' LSA kode. LSA koden er minimumskrav. Produsenter av overleveringsdrakter legger også inn kvaliteter ut over minimumskrav. En slik kvalitet er beskaffenheten av sålen under foten som kan få utforming med bruk av gummi.

Tilstrekkelig sklisikring av personell vurderes til å være ivaretatt når det dokumenteres ~~at FAT og SAT er utført~~, at helikopterdekket friksjonskoeffisient er i henhold til minimumskravet, og at implementerte prosedyrer for vedlikehold av sklisikkerhet blir gjennomført, samt at frekvens for verifikasjon av sklisikkerhet blir etterlevd.

Helikopterdekkoperatøren
På forespørsel fra en helikopteroperatør må helikopterdekkoperatøren kunne dokumentere til enhver tid at alle de faktorer som kan påvirke helikopterdekkets overflateegenskaper er identifisert og overvåket gjennom prosedyrer og tiltak som sikrer tilstrekkelig sklisikkerhet.

Dedicated to innovation in aerospace

COMPANY CONFIDENTIAL

NLR-CR-2023-458 | January 2024

Friction tests on a helideck for Aircontact Services

Measurements according to CAP437 edition 8

CUSTOMER: Aircontact Services



Royal NLR - Netherlands Aerospace Centre

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NLR-CR-2023-458 | January 2024

Friction tests on a helideck for Aircontact Services

Measurements according to CAP437 edition 8

CUSTOMER: Aircontact Services

AUTHOR(S):

G.J. de Jong NLR

Royal NLR - Netherlands Aerospace Centre

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CUSTOMER	**Aircontact Services**
CONTRACT NUMBER	**PO ACS-HD-2023-01**
OWNER	**NLR**
DIVISION NLR	**Aerospace Vehicles**
DISTRIBUTION	**Limited**
CLASSIFICATION OF TITLE	**UNCLASSIFIED**

APPROVED BY:		
AUTHOR	**REVIEWER**	**MANAGING DEPARTMENT**
G.J. de Jong	R.P. Beukema	P. Arendsen
DATE 08/01/24	DATE 10/01/24	DATE 15/01/24

Summary

The NLR was contracted by Aircontact Services in Norway to perform friction tests on a helideck. It consisted of a flat sample with dimensions 600mm x 600mm that is composed of aluminium extruded deck planks. The top surface was supplied with an antiskid coating that consists of:

- Primer 200µm + 600µm with added antiskid grit size 1.4-2.0mm in quantity 2kg/m^2.
- Top coat of 75-100 µm.

The deck was designated ACS-Deck 1.

The friction coefficients were determined by towing a Sikorsky S92 helicopter wheel under realistic vertical load over the deck sample in the wet condition. The tests were executed as to comply with CAP 437 edition 8.

The following minimum average friction value (which is normative for the deck) was obtained:
ACS-Deck 1 : Mu=0.71 in the NT case.

The results are presented in tabular and graphical form.

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1 Introduction

The NLR was contracted by Aircontact Services in Norway to perform friction tests on a helideck. The deck was designated ACS-Deck 1.

The friction coefficients were determined by towing a Sikorsky S92 helicopter wheel under realistic vertical load over the deck sample in the wet condition. The tests were executed as to comply with CAP 437 edition 8.

This report describes the deck, the test program and presents the outcome of the tests.

2 Test articles

The test article was supplied to NLR by Aircontact Services. It consists of a flat sample with dimensions 600mm x 600mm that is composed of aluminium extruded deck planks. The top surface is supplied with an antiskid coating that consists of:

- Primer 200µm + 600µm with added antiskid grit size 1.4-2.0mm in quantity 2kg/m^2.
- Top coat of 75-100 µm.

Figure 2-1 to Figure 2-3 show pictures of the deck.

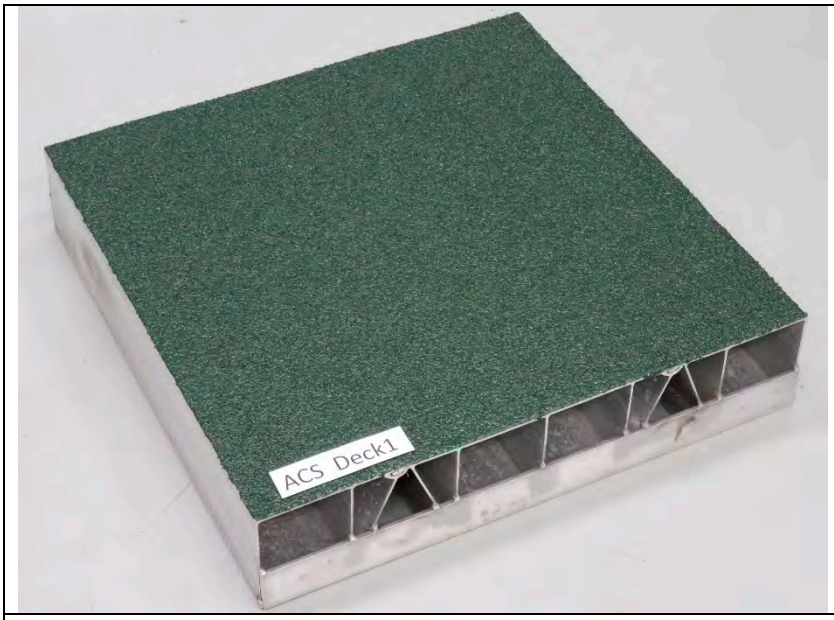


Figure 2-1: Overview of deck specimen ACS-Deck1



Figure 2-2: Detail of deck specimen ACS-Deck1. (Scale in mm)

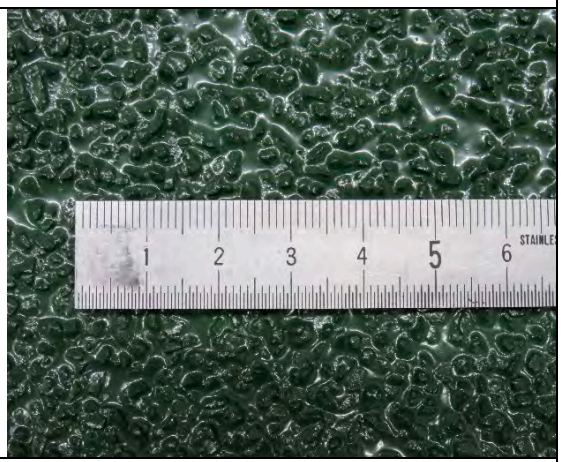


Figure 2-3: Detail of deck specimen ACS-Deck1. (Scale in mm)

3 Test Program

3.1 General background

In 2010 NLR performed an investigation into the friction properties of aluminium helicopter decks under contract to the UK-CAA. The investigation and its results are reported in NLR report NLR-CR-2011-146, *"Friction measurements of tyres on aluminium helicopter decks"* (Ref. 1). From these tests a test protocol was deduced that the UK-CAA incorporated in CAP 437 edition 8. The text of this document concerning the friction tests is presented in Appendix A of this report.

3.2 Helicopter wheel and tyre selected

CAP437 edition 8 prescribes a contact area between tyre and deck of 200cm² at least and a footprint pressure of 1N/mm2. From Ref.2 and footprint measurements reported in Ref.1 it was concluded that the reported S92 footprint pressure of 0.86N/mm² is closest to the required 1N/mm² of all tyres mentioned. Achieving 1N/mm² seemed feasible. Moreover, the S92 is a commonly used helicopter. Therefore the S92 wheel was selected to be used in the tests.

The matching tyre for the S92 wheel is a Dunlop tyre, part no. DR30525T size 19.5x6.75-8. The prescribed inflation pressure of the tyre for use on the S92 is 115psi-125psi.

3.3 Tyre inflation pressures, wheel load and footprint pressures

A number of footprint tests were performed in order to establish vertical load / inflation pressure combinations that:

- Result in the footprint pressure and footprint area required by CAP 437 edition 8
- Are within realistic operational ranges
- Can be worked up by the NLR test set-up

In order to attain 1N/mm² unrealistic high vertical loads had to be applied that resulted in large horizontal loads that could not be worked up by the test setup. A vertical load of 20kN and an inflation pressure of 125psi were selected resulting in a footprint pressure of 0.96N/mm² and a footprint area of 20.8cm². Both the selected vertical load and the selected inflation pressure are within the operational range. The value of 0.96N/mm² was submitted to the UK-CAA and was accepted by them as being suitable (Ref.3).

A lower footprint pressure tends to result in higher indicated friction values, see Ref. 1.

3.4 Applied wheel orientation/deck towing direction combinations

The test method that has been used is designed for decks that have pronounced direction-dependent properties.

As a rule, four combinations of wheel orientation / deck towing direction as shown in Figure 3-1 are exercised.
The combinations are designated:

- RL: The deck is towed in the Rolling direction of the wheel, parallel to the extruded ribs, which is the Longitudinal deck direction.
- RT: The deck is towed in the Rolling direction of the wheel, Transverse to the extruded ribs.
- NL: The deck is towed in the Non-rolling direction of the wheel, parallel to the extruded ribs, which is the Longitudinal deck direction.
- NT: The deck is towed in the Non-rolling direction of the wheel, Transverse to the extruded ribs.

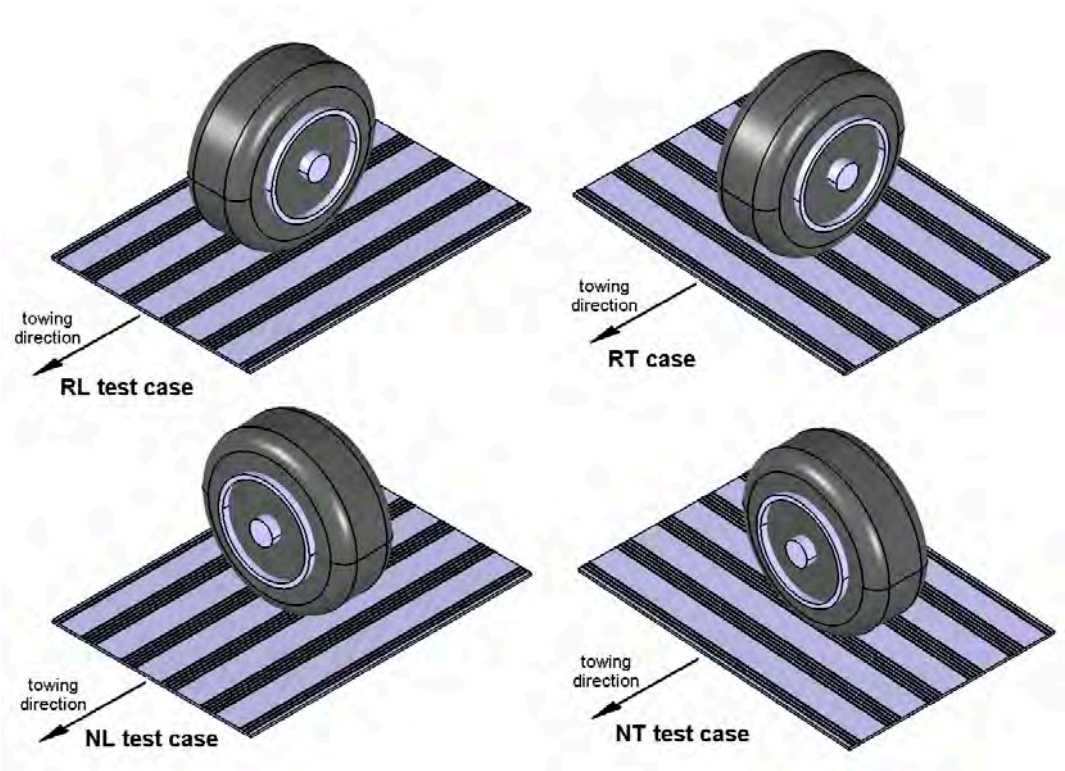


Figure 3-1: Overview of the four deck tow direction / wheel orientation combinations that were exercised

Although the surface of the deck under investigation can be expected to show isotropic friction properties, all four combinations were exercised on this deck. The “L” direction corresponded to the direction of extrusion.

3.5 Test conditions

3.5.1 Towing velocity and distance

The towing velocity of the deck relative to the wheel has been 100 mm/min. All runs were made over a range of 300 mm.

3.5.2 Temperature

All tests were conducted at room temperature.

3.5.3 Wet/dry condition

All tests were conducted in the wet condition, this being the worst case.

3.5.4 Number of repetitions

In each test case as shown in Figure 3-1 three runs were performed.

4 Test setup

4.1 Background of the development of the test setup

In 2010 the NLR was contracted by the UK-CAA to perform an investigation into the friction properties of aluminium helicopter decks. The setup described in this chapter was developed as a tool for these investigations.

4.2 Definition of the friction coefficient

The friction coefficient (Mu) is defined as:

Mu = Ffriction / Fweight

where (see *Figure 4-1*):

Fweight = the normal load acting between the deck sample and the helicopter wheel.
Ffriction = the load parallel to the deck surface that is exerted by the (moving) deck on the helicopter wheel.

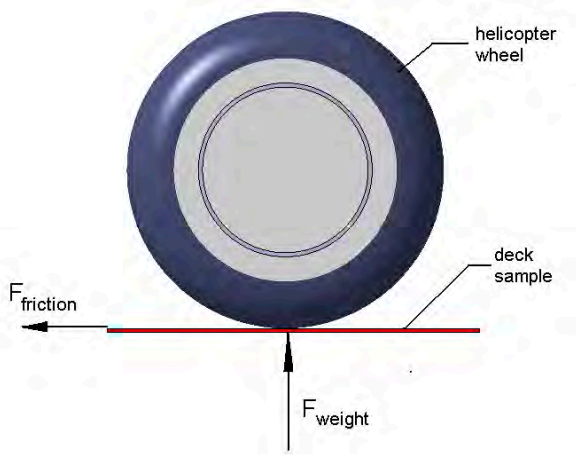


Figure 4-1: Definition of the loads that determine the friction coefficient

4.3 Principle of the test setup

The test setup was designed and built to simulate reality as close as possible. Actual helicopter wheels can be mounted in the rig together with real deck samples. Full scale operational vertical wheel loads (Fweight) can be applied and measured. The deck sample is towed horizontally under the wheel, and the load that is exerted by the deck on the wheel (Ffriction) is measured. Both Fweight and Ffriction are sampled continuously and the quotient (Mu) is calculated continuously from corresponding samples.

4.4 Description of the test rig

4.4.1 Hardware

The test rig was built around an Avery servo-hydraulic test machine owned by NLR. This machine consists of four columns, a lower movable support (see Figure 4-2) and a fixed upper support that is connected to the four columns (see Figure 4-3). The movable support can traverse in the (vertical) z-direction. A sliding support is mounted on top of this movable support which enables displacement in the (horizontal) x-direction. It is actuated by an electrically driven spindle that is also mounted on the movable Avery support. A water tray is mounted on top of the horizontal sliding support on which the deck sample under test is placed.

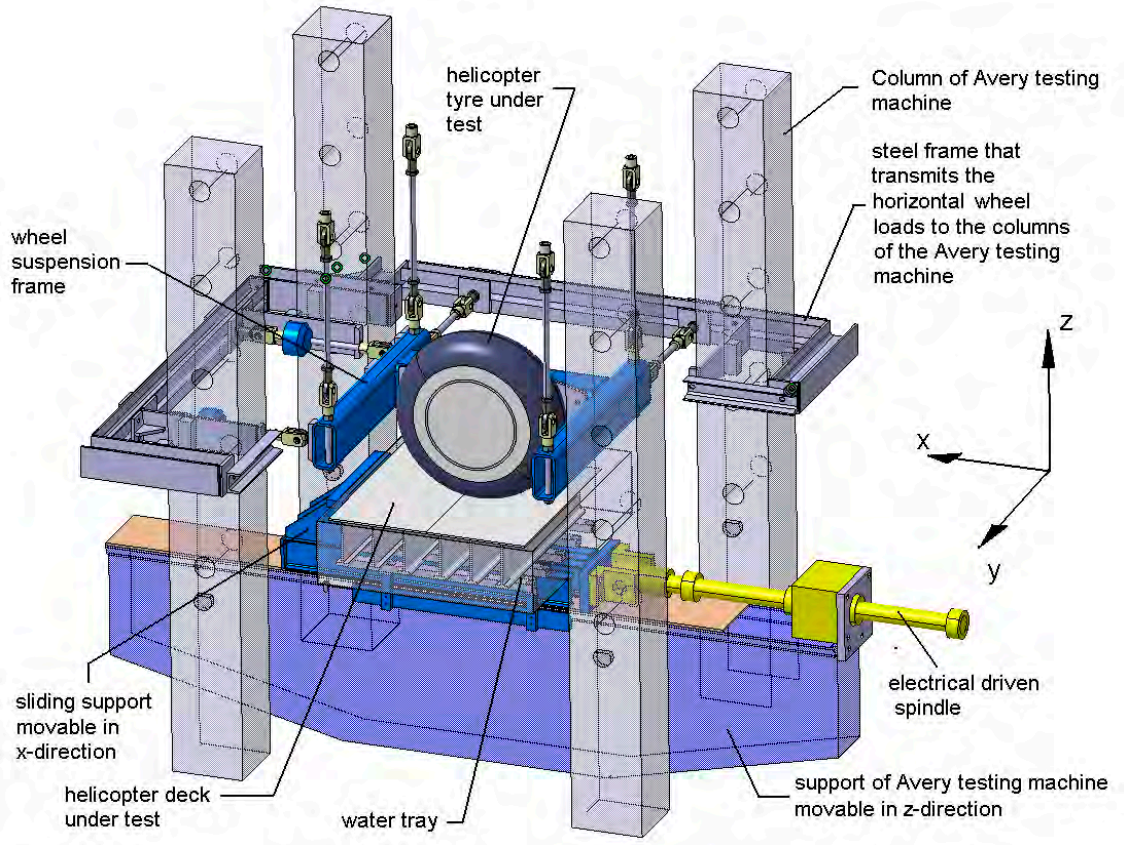


Figure 4-2: Drawing of the test setup. The Avery columns and the water tray are drawn transparent for clarity. The H-shaped wheel suspension frame is suspended from the fixed support of the Avery testing machine. This latter support is not drawn to aid clarity, see also Figure 4-3



Figure 4-3: Photograph of the test set up. The wheel is mounted with its rolling direction parallel to the towing direction of the deck



Figure 4-4: Water is being pumped over the deck sample in front of the tyre in order to simulate the wet condition.(The deck on the picture is not the deck tested in this document.)

The water tray contains a few centimetres of water that is continuously pumped over the tyre and deck surface in order to simulate the wet condition (see Figure 4-4).

The helicopter wheel under test is mounted to the axle of an H-shaped frame (see Figure 4-5). A sprocket wheel prevents rotation of the wheel on the axle.



Figure 4-5: The H-shaped frame with the wheel mounted

The H-shaped frame is connected to the fixed support of the Avery test machine in the (vertical) z-direction by means of four threaded rods. In the x-y plane the frame is fixed by another four rods of which the two pointing in x-direction are supplied with load cells, see Figure 4-7 and Figure 5-1. All rod connections are fitted with swivel joints. Consequently the rods can only transfer loads that are parallel to their longitudinal axes. Figure 4-6 shows a detailed view of a rod end connection.



Figure 4-6: Detailed view of a rod end connection

The H-shaped frame can be mounted in the setup in two ways, either with the axle in the y-direction or in the x-direction. This allows testing with the rolling direction of the wheel either parallel to or perpendicular to the towing direction of the deck sample.

4.4.2 Load transfer and load measurement

The vertical load Fweight (see Figure 4-1 and Figure 4-7) is applied by pressing the deck sample against the wheel by means of the moveable support of the Avery test machine. This is effected in a load controlled manner. The vertical load is transferred to the four rods pointing in the z-direction. The horizontal friction load is transferred by the two rods in x-direction and is measured by the two load cells in these rods. The value of Ffriction is:

Ffriction = Fx1 + Fx2.

The y-rods are included to help stabilize the H-shaped wheel frame.

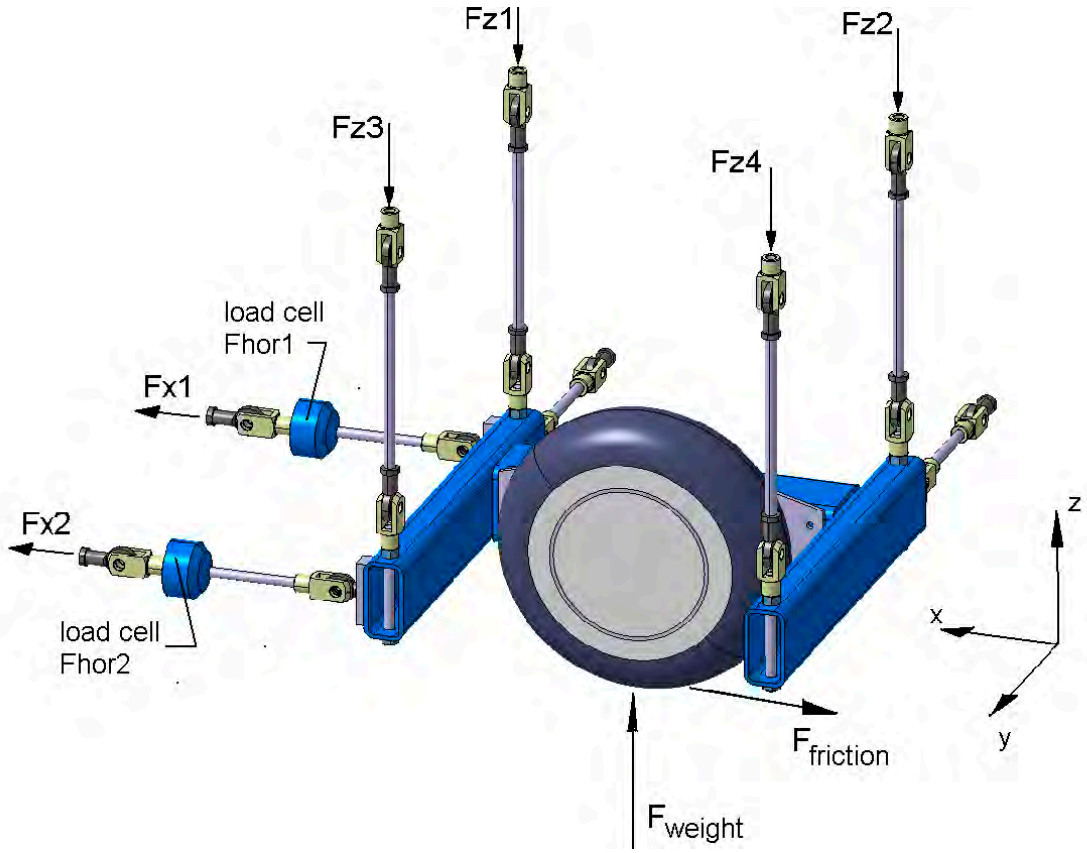


Figure 4-7: Principle of the load transfer and load measurement in the test rig

5 Instrumentation of the test set-up

5.1 Calibration of equipment

All equipment was calibrated under the quality system (AQAP 2110) that is applied at the NLR. All calibrations are traceable to national or international standards.

5.2 Control system of the Avery testing machine

The Avery test machine is controlled by an Instron retrofit control system, model ISRS-R-Avery. The vertical wheel load (Fweight) is measured using the load cell of the Avery machine. The Avery machine set up was calibrated for load by the NLR Load Calibration Facility. The calibration was performed on 9 November 2023 with a validity of one year. The calibration certificate is shown in Appendix B.

5.3 Data acquisition system

All signals needed in the friction measurements were measured using a Peekel Autolog3000 data acquisition system with NLR designation no.Dyn8. This system was calibrated by the NLR Electronics Calibration Facility (ASAQ). The calibration was performed from 20 June 2023 till 30 June 2023.The validity of the calibration is one year. The calibration reports are shown in Appendix C.

5.4 Load cells

The friction loads were measured by means of two load cells mounted in the x-direction rods, see Figure 4-7 and Figure 5-1. The load cells were calibrated for load by the NLR Load Calibration Facility on 24 April 2023 with a validity of one year. The calibration certificate is shown in Appendix D.

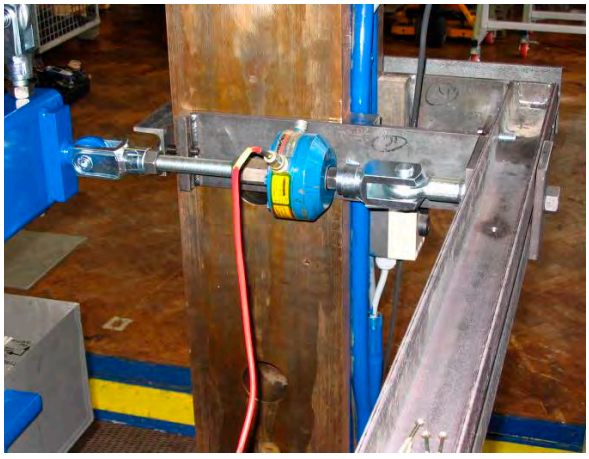


Figure 5-1: Close up of load cell Fhor2. Note the swivel joints at the rod end

5.5 Velocity measurement

The velocity of the sliding support in x-direction is measured using a potentiometric cable extension sensor, see Figure 5-2. The velocity of the support is calculated by dividing the measured displacement of two subsequent samples by the sample time of the data acquisition system. The transducer was prior to testing functionally checked by the NLR test house (AVTH).

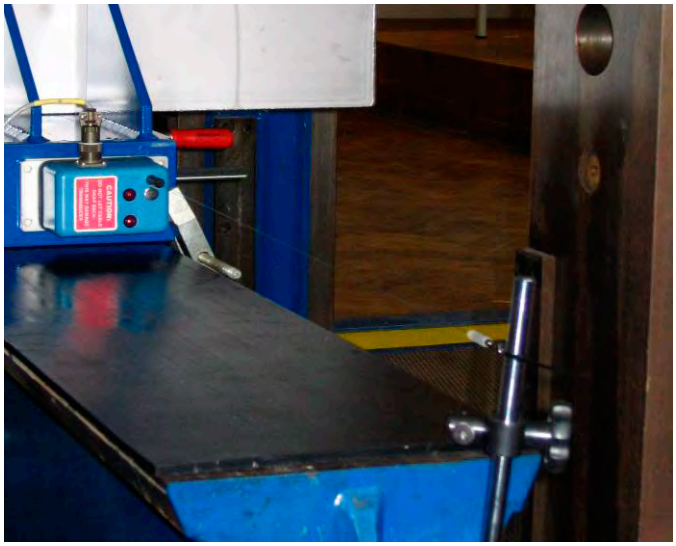


Figure 5-2: The cable extension transducer mounted to the horizontal sliding support

5.6 Inflation pressure

The inflation pressure of the tyres was measured using a GE Druck DPI 800P pressure indicator. The device was calibrated on 1 May2023 with a validity of 1 year by the Trescal company. The certificate is shown in Appendix E.

6 Execution of the tests

6.1 Time and place

The tests were executed on the premises of the NLR, Voorsterweg 31, 8316PR, Marknesse, The Netherlands on 8 and 12 December 2023.

6.2 Witnessing

The tests were not witnessed.

6.3 Tyre used

The tyre used was a Dunlop tyre DR30525T size 19.5x6.75-8.

6.4 Peculiarities observed during testing

No peculiarities were observed during testing.

7 Results

In this report the dynamic friction coefficient is used as an indicator for the friction quality of a helideck. The dynamic friction coefficient is the friction coefficient that is measured after the tyre has overcome the static friction and has started sliding over the deck.

All measured dynamic friction coefficients are presented in tabular form.
The maximum and minimum dynamic friction values that are presented for each test case are the extremes that occurred during the three subsequent repetitions of that test case.
The presented “Average value dynamic friction” of a test case is obtained by the averaging of all dynamic friction samples that were taken during the three subsequent repetitions of the test case in question.

In addition, the results are presented in graphical form to assist interpretation.

Tyre	Vertical load on wheel	Tyre inflation pressure	Temperature	Towing velocity	Deck designation	Wheel orientation	Deck tow direction	Repetitions	Maximum value dynamic friction	Average value dynamic friction	Minimum value dynamic friction	Run no.	See Fig.
	[kN]	[psi]	[°C]	[mm /min]	[-]	[-]	[-]	[-]	[-]	[-]	[-]		
S92	20	125	20	100	ACS-Deck1	R	L	3	0.83	0.72	0.69	000-002	7-1
S92	20	125	20	100	ACS-Deck1	R	T	3	0.82	0.72	0.69	003-005	7-2
S92	20	125	20	100	ACS-Deck1	N	L	3	0.88	0.73	0.72	006-008	7-3
S92	20	125	20	100	ACS-Deck1	N	T	3	0.77	0.71	0.68	009-011	7-4

Table 1: Results of all measurements. Presented are the maximum and minimum dynamic friction values that occurred during the three subsequent repetitions of each test case, together with the average of the dynamic values of all samples taken during the three subsequent runs

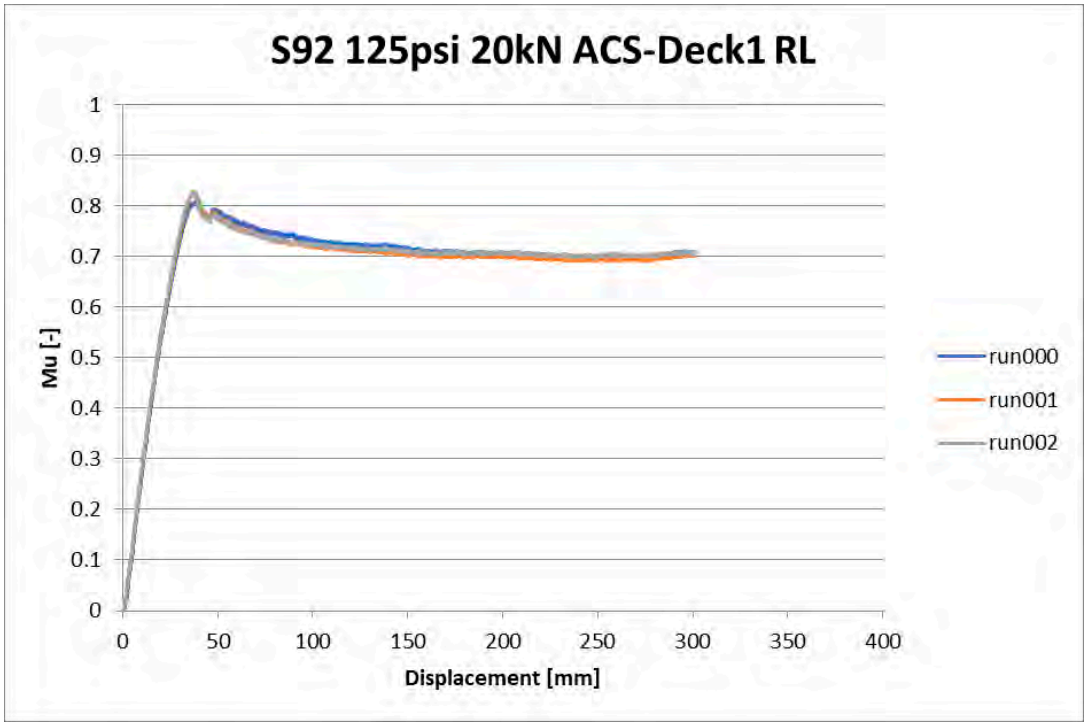


Figure 7-1: Results of the RL measurements on test article ACS Deck1

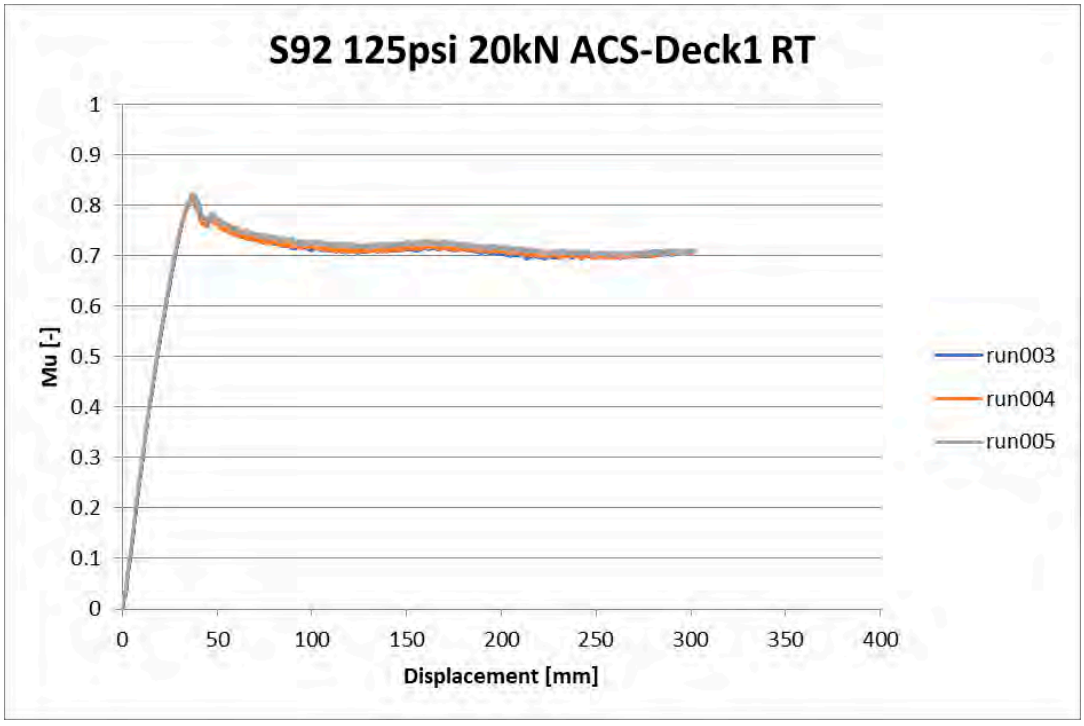


Figure 7-2: Results of the RT measurements on test article ACS Deck1

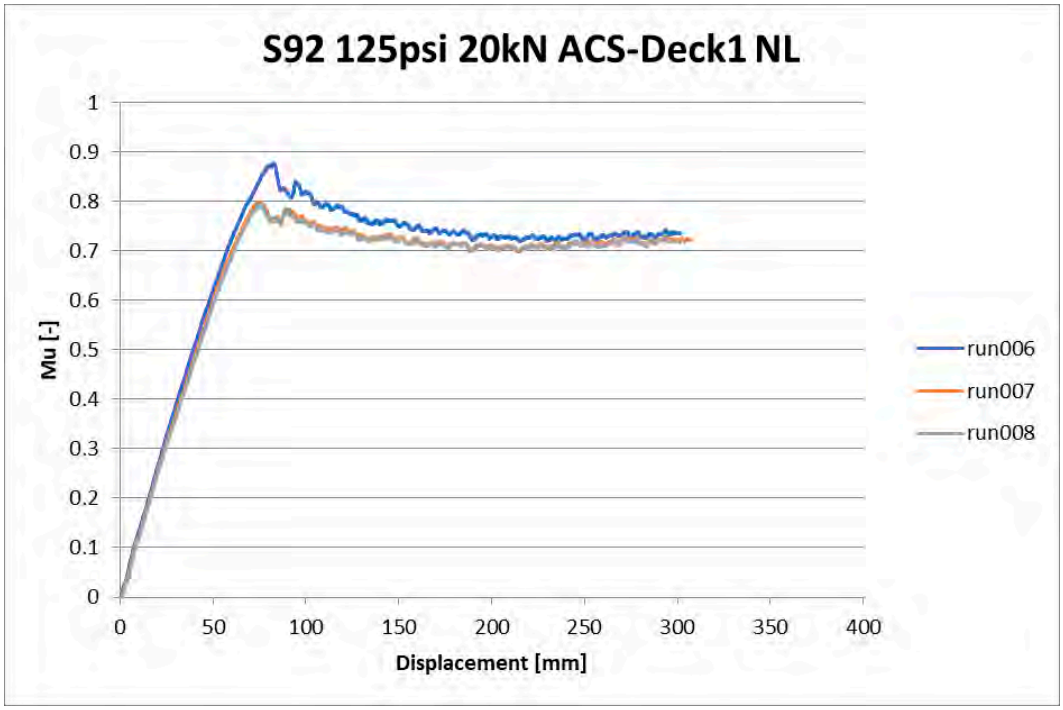


Figure 7-3: Results of the NL measurements on test article ACS Deck1

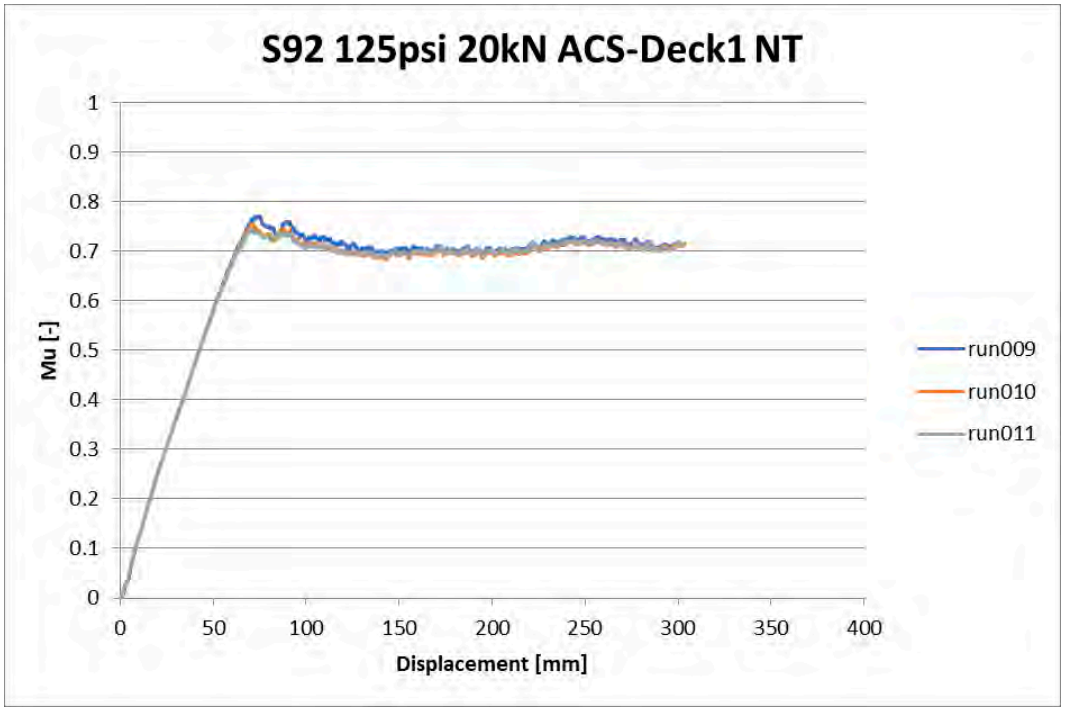


Figure 7-4: Results of the NT measurements on test article ACS Deck1

8 Conclusion

The following minimum average friction value (which is normative for the deck) was obtained:
ACS Deck1: Mu=0.71 in the NT case.

9 An additional word on static friction results

According to CAP437 edition8 the static friction values of a deck are no criterion in the assessment of a deck's normative friction value. However, in some cases knowledge of the static friction may be required.

The static friction coefficients of a deck can be retrieved from the results that are obtained by the NLR full scale test method.

Figure 9-1 shows a graph of friction values as they are usually presented. During the first part of a friction test, starting from 0mm onward, the tyre is deforming but is not sliding over the deck. Thus static friction is being build-up. After a certain amount of displacement (in the graph of Figure 9-1 about 80mm) and matching tyre deformation the static friction reaches its maximum and is then overcome: the tyre starts sliding over the deck, resulting in a reduction of the friction coefficient. At this point of transition from static to dynamic friction, the maximum static friction occurs. In all cases this maximum static friction value equals the maximum dynamic friction that was measured. This maximum dynamic value is stated in Table 1 in column "maximum value dynamic friction".

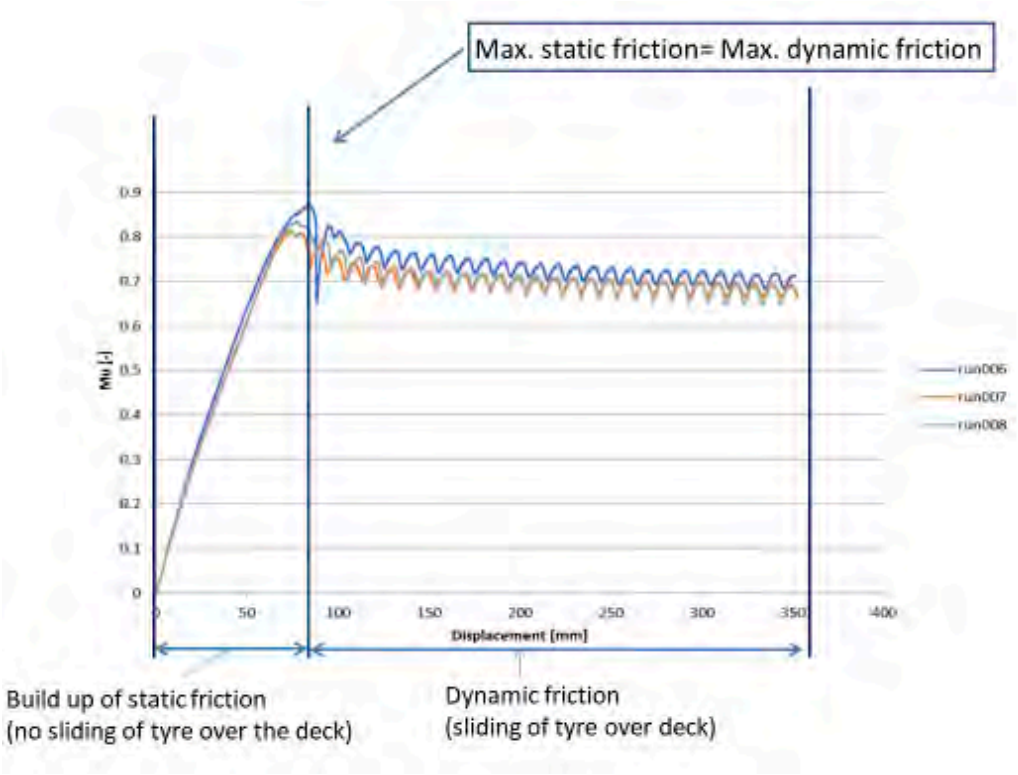


Figure 9-1: The transition from static to dynamic friction and the relation between static and dynamic friction coefficient

The static friction values that are thus obtained are presented in Table 2.

Table 2: Presented are the maximum static friction values that occurred during the three subsequent repetitions of each test case

Tyre	Vertical load on wheel	Tyre inflation pressure	Temperature	Towing velocity	Deck designation	Wheel orientation	Deck tow direction	Repetitions	Maximum value static friction	Run no.	See Fig.
	[kN]	[psi]	[°C]	[mm /min]	[-]	[-]	[-]	[-]	[-]		
S92	20	125	20	100	ACS-Deck1	R	L	3	0.83	000-002	7-1
S92	20	125	20	100	ACS-Deck1	R	T	3	0.82	003-005	7-2
S92	20	125	20	100	ACS-Deck1	N	L	3	0.88	006-008	7-3
S92	20	125	20	100	ACS-Deck1	N	T	3	0.77	009-011	7-4

In case the maximum horizontal towing load that occurred is required, this value can be obtained by multiplying the maximum static friction by 20kN, see Section 4.2. This 20kN is the vertical wheel load applied during testing.

10 References

1. *Friction measurements of tyres on aluminium helicopter decks,* NLR-CR-2011-146, G.J. de Jong.
2. OFFSHORE HELIDECK DESIGN GUIDELINES, John Burt Associates Limited / BOMEL Limited for the Health and Safety Executive.
3. e-mail by Dave Howson (CAA) to Kevin Payne (CAA) and Jan de Jong (NLR) dated 16-november 2016 12:34 titled "*Fw: Testing with S92 and edition8 requirements".*
4. *Guidelines for the determination of calibration intervals of measuring instruments,* Guidance ILAC-G24 edition 2007, International Laboratory Accreditation Cooperation.

Appendix A Text of CAP 437 edition 8 concerning pass/fail criteria

The test protocol that is being published in CAP 437 8th Ed. says:

3.42 For profiled helideck surfaces, typically constructed from extruded aluminium planks, new helidecks (i.e. helidecks commissioned on or after 01 January 2017) should be tested as described in paragraph 3.43. Legacy helidecks (i.e. helidecks commissioned before 01 January 2017) may be tested as described in paragraph 3.44.

NOTE: For the purposes of this paragraph and paragraphs 3.43 and 3.44, the date of commissioning is the date of the first helideck certificate issued prior to the commencement of routine operations.

3.43 Helidecks commissioned on or after 01 January 2017: A specimen should be submitted to a suitably qualified and independent test facility for testing at full scale. The testing should normally comprise the following:

- use of a representative helicopter wheel and tyre with a tyre contact area of at least 200 cm^2;
- testing at a vertical load to produce a tyre contact pressure of at least 0.95 N/mm^2 and ideally 1 N/mm^2, and also within the normal range of loads and tyre pressures for the aircraft wheel being used for the testing;
- testing in the wet condition;
- testing in all four permutations of wheel and surface profiling directions, i.e. wheel in rolling (R) and non-rolling (N) directions, along, i.e. longitudinal (L), and across, i.e. transverse (T), the ridges of the profiling to give the four test conditions of RL, RT, NL and NT;
- at least three test runs to be performed for each test condition;
- the result for each test run should be the average surface friction value for the run, excluding the initial peak due to static friction;
- the result for each test condition should be the average of the (at least three) test runs for that condition;
- the overall result for the helideck specimen should be the lowest of the results for the four conditions.

NOTE 1: Each test run may be performed using a 'fresh', undamaged section of the test tyre.

NOTE 2: For the area outside the TD/PM Circle, an inadequate surface friction value (i.e. < 0.5) may be rectified by grit blasting or by applying a suitable non-slip paint coating. For the area inside the TD/PM Circle (< 0.6 for fixed helidecks, < 0.65 for moving helidecks), removal of the profiling prior to grit blasting or painting is recommended or, alternatively, the fitment of a helideck net – see paragraph 3.45 below.

NOTE 3: The testing described in this paragraph represents a once-off type approval and no further in-service monitoring or testing is required unless the helideck has to be provided with a micro-texture finish (e.g. grit blasting or friction paint) in order to meet the minimum surface friction values required. In that case, the in-service monitoring/testing protocol specified in paragraph 3.39 should be applied with the friction tester to be used being calibrated using the full-scale test results. The calibration should comprise multiplying the friction tester readings using the following scaling factor:

$$Scaling\ factor = \frac{RL\ test\ condition\ full\ scale\ results}{L\ average\ friction\ tester\ results}$$

The friction tester readings used to calculate the scaling factor should ideally be measured on the same test specimen used for the full scale tests or, at least, a specimen in the same nominal condition, e.g. a sample from the same plank or the same plank production batch. Testing should be performed in a direction parallel to the ribs of the surface profiling only.

NOTE 4: Providing a lasting non-slip paint finish to the tops of ribs can be challenging. Grit blasted micro-texture finishes are likely to be more effective and more durable than non-slip paint finishes on profiled helideck surfaces.

To be used without any non-slip coating/finish on any deck, the worst result should be at least 0.5 mu.

To be used without any non-slip coating/finish or net on a fixed deck, the worst result should be at least 0.6 mu.

To be used without any non-slip coating/finish or net on a moving deck, the worst result should be at least 0.65 mu.

Appendix B Calibration certificate of the Avery test machine

This Appendix contains the calibration certificate of the Avery 2000kN test machine.
For this test program the machine was calibrated in upto 25kN.
The calibration was executed on 9 November 2023 with a validity of one year.

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CALIBRATION
RvA K 042

NLR – Royal Netherlands Aerospace Centre
Laboratory of force calibration
Department Structures Testing and Evaluation

Calibration-certificate

Page 1 of 4

Certificate number : 2023-028

Applicant	:	Att. Mr. G.J. de Jong, department AVTH Netherlands Aerospace Centre, Voorsterweg 31 8316 PR Marknesse
Order number	:	03282.3.11.8
Instrument	:	2 MN (2000 kN), Avery material testing machine
manufacturer	:	Avery LTD, Birmingham, Engeland
type	:	A 807 / 1475
serial number	:	E 47327
Calibration method	:	Compression calibration with increasing load levels, load range: 10 kN to 25 kN.
Environmental conditions during calibration	:	Temp.: 21.7 °C – 22.5 °C ± 1 °C. RH: 43.1 % - 45.8 % ± 2 % RH
Date/period/location of calibration	:	9 November 2023 at the Netherlands Aerospace Centre, Voorsterweg 31 8316 PR, Marknesse
Results	:	See page 2 to 4 incl.
Uncertainty	:	The reported expanded uncertainty is based on the standard uncertainty of the measurement multiplied by a coverage factor *k*, such that the coverage probability corresponds to approximately 95 %. The standard uncertainty has been determined in accordance with EA-4/02. Uncertainty of the measurement: see tables 1 and 2
Traceability		The measurements have been executed using standards for which the traceability to (inter)national standards has been demonstrated towards the Dutch Accreditation Council RvA.

date : 8-12-2023

name : G. Bos

function : Head of force calibration laboratory

signature

Gert Bos
2023.12.22
08:59:18
+01'00'

P.O. Box 153,
8300 AD Emmeloord
The Netherlands
Telephone : + 31(0)885113113
E-mail : info@nlr.nl
Internet : www.nlr.nl

The Dutch Accreditation Council (RvA) is member of the European Co-operation for Accreditation (EA) and is one of the signatories to the EA Multilateral Agreement and to the ILAC Mutual Recognition Arrangements (MRA) for the mutual recognition of calibration certificates.

Reproduction of the complete certificate is allowed. Parts of the certificate may only be reproduced with written approval of the calibration laboratory.
This certificate is issued provided that the RvA does not accept any liability.

Fig. B1: Page 1 of the calibration certificate of the Avery test machine

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CALIBRATION
RvA K 042

NLR – Royal Netherlands Aerospace Centre
Laboratory of force calibration
Department Structures Testing and Evaluation

Calibration-certificate

Page 2 of 4

Certificate number : 2023-028

Calibration-results:

In table 1 is:

F_i	=	Indicated load in kN generated by the Avery material testing machine
1st, 2nd and 3rd	=	Measured output values of the calibration amplifier presented in mV/V
Mean	=	Mean of the three measured output values 1st, 2nd and 3rd presented in mV/V
F_a	=	Actual load in kN generated by the Avery material tesing machine
q	=	Deviation, the difference between F_i an F_a, expressed in % of F_a
b	=	Repeatability, the difference between the highest and lowest values of 1st, 2nd and 3rd expressed in % of Mean

In Figure 1 the deviation q is presented as a percentage of F_a.

The presented values are valid in a measurement range as in each individual table is presented. This means that the measurement results are related to a measurement range between the first and the last measurement value, excluding the zero values. See remark at table 2.

In table 2 is:

F_i v	=	Indicated load in kN derived from the voltmeter (10 V equals 100 kN)
1st, 2nd and 3rd	=	Measured output values of the voltmeter presented in V
Mean	=	Mean of the three measured output values 1st, 2nd and 3th presented in V
F_a machine	=	Actual load in kN generated by the Avery material tesing machine
qv	=	Deviation, the difference between F_a machine and F_i voltmeter, expressed in % of F_a machine
bv	=	Repeatability, the difference between the highest and lowest values of 1st, 2nd and 3rd expressed in % of Mean
Unc	=	Measurement uncertainty (k=2)

Remark: the analog output of the Instron Controller was used for measuring the output voltage. The setting used was: tab-Tools\configure\controllers\ISRS\ch 1\2000% which means that 100 kN equals 10 Volt.

Fig. B2: Page 2 of the calibration certificate of the Avery test machine

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Laboratory of force calibration
Department Structures Testing and Evaluation

Calibration-certificate

Page 3 of 4

Certificate number : 2023-028

TABLE 1 Compression calibration of the 100 kN loadrange of the 2000 kN AVERY material testing machine (display readout) using the H20t/D ref. standard
FILE: 45G01DRU.NLR loadrange: 100kN (25kN compression)

Fi kN	1st mV/V	2nd mV/V	3th mV/V	mean mV/V	Fa kN	q %	b %
0.000	0.00000	0.00000	0.00000	0.00000	0.0	-	-
10.00	-1.00387	-1.00652	-1.00634	-1.00558	10.03	-0.32	0.26
12.00	-1.20366	-1.20881	-1.21257	-1.20835	12.05	-0.44	0.74
14.00	-1.40523	-1.40492	-1.40381	-1.40465	14.01	-0.05	0.10
16.00	-1.60583	-1.60775	-1.59833	-1.60397	15.99	0.05	0.59
18.00	-1.80164	-1.80587	-1.79521	-1.80091	17.95	0.27	0.59
20.00	-1.99636	-2.00042	-2.00479	-2.00052	19.94	0.32	0.42
22.00	-2.20519	-2.20426	-2.20451	-2.20465	21.97	0.15	0.04
25.00	-2.50239	-2.49684	-2.49678	-2.49867	24.89	0.45	0.22
0.000	-0.00001	0.00000	0.00000	-0.00000	0.0	-	-

Measurement uncertainty : 0.86 % (k=2)

Remark: a correct zero adjustment of the machine is an important factor in determining the right value of the Fa of the machine. An incorrect zero or zero-offset can adversaly affect the accuracy of the Load Fa of the machine. See also remark at table 2.

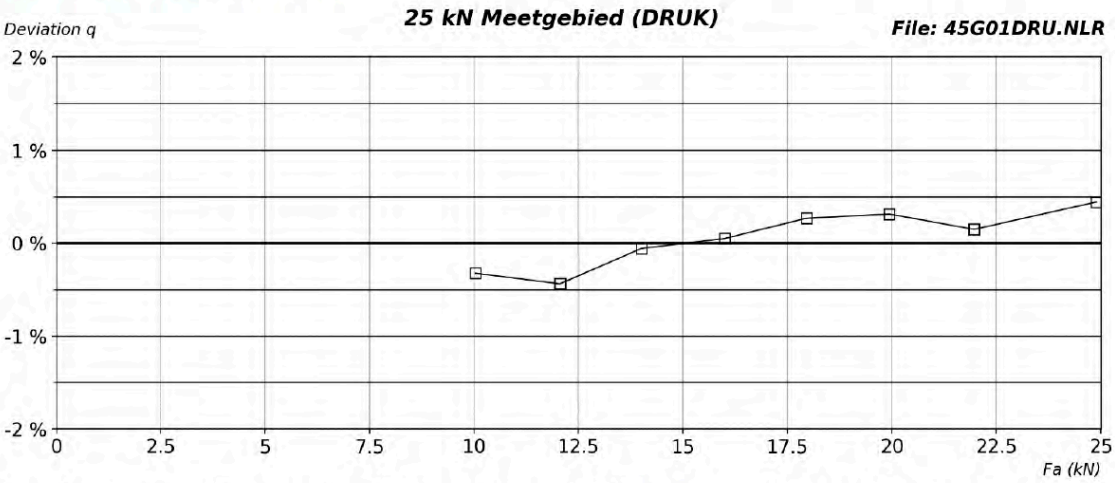


Fig. 1 Compression calibration of the 25 kN loadrange of the 2000 kN Avery material testing machine using the H20t/D ref. standard

Fig. B3: Page 3 of the calibration certificate of the Avery test machine

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CALIBRATION
RvA K 042

NLR – Royal Netherlands Aerospace Centre
Laboratory of force calibration
Department Structures Testing and Evaluation

Calibration-certificate

Page 4 of 4

Certificate number : 2023-028

TABLE 2 Compression calibration of the 100 kN loadrange of the 2000 kN AVERY material testing machine (Voltmeter readout) using the H20t/D ref. standard
FILE: 45T01DRU.NLR loadrange: 100kN (25kN compression)

Fa Machine kN	1st V O L T V	2nd M E T V	3rd E T E R V	mean V	Fiv Voltmeter kN	qv %	bv %	Unc.* %
0.00	0.000	0.000	0.000	0.000	0.000	-	-	-
10.03	0.997	0.997	0.997	0.997	9.970	-0.60	0.00	0.67
12.05	1.196	1.196	1.196	1.196	11.96	-0.75	0.00	0.98
14.01	1.396	1.396	1.396	1.396	13.96	-0.36	0.00	0.50
15.99	1.596	1.596	1.596	1.596	15.96	-0.19	0.00	0.78
17.95	1.795	1.795	1.795	1.795	17.95	0.00	0.00	0.76
19.94	1.995	1.995	1.995	1.995	19.95	0.05	0.00	0.59
21.97	2.194	2.194	2.194	2.194	21.94	-0.14	0.00	0.50
24.89	2.494	2.494	2.494	2.494	24.94	0.20	0.00	0.50
0.00	0.000	0.000	0.000	0.000	0.000	-	-	-

* Measurement uncertainty (k=2)
Voltmeter: KEITHLEY 181 nanovoltmeter THA 00063, NLR calibrated 17-01-2023

The material testing machine is set to a load Fi in kN while reading the Voltmeter in Volts representing a load Fiv in kN.
The deviation qv of the voltmeter is expressed as a % of the Fa of the machine.
The repeatability b of the voltmeter is expressed as a % of the mean of the three measurements of the voltmeter.

The actual value of the load measured with the reference standard and the relation with the voltmeter reading is showed in table 2.

Remark:
The machine software (indication in kN and in Volt) was set to zero just before every calibration sequence (only when necessary). This zero setting was carried out without movement of the machine piston.
All measured calibration results and uncertainties are due to these zero settings.
Also any non-zero indication at the end of a calibration sequense was taken into account as contribution in the measurement uncertainty.

Fig. B4: Page 4 of the calibration certificate of the Avery test machine

Appendix C Calibration reports of the Autolog3000 data acquisition system

This Appendix gives calibration data of the Peekel Autolog3000 (NLR no.Dyn8) data acquisition system that was used. The calibration was performed from 20 June 2023 till 30 June 2023 with a validity of 1 year. In order to reduce the amount of data, only the title pages of the reports are presented.

Dedicated to innovation in aerospace

CALIBRATION RvA K 038

Royal NLR – Netherlands Aerospace Centre
Facility Instrument Maintenance
Department Electromagnetics, Energy Management & Qualification

Calibration-certificate

Page 1 of 3

Certificate number : FIM20230701/00

Applicant:	Royal NLR - Netherlands Aerospace Centre Department Structures Testing & Evaluation Voorsterweg 31 8316PR Marknesse, The Netherlands
Calibrated instrument:	
Manufacturer:	Peekel
Type:	Autolog3000
Serial Number:	1550066_Dyn8
Calibration method:	The CA3460 cards were placed in the Autolog3000 system and are calibrated for the functions Quarter Bridge, DCV and Transducer Full Bridge in accordance with procedure P13.CA3460_QB602_DCV5700_FBSSAM_PT602. This certificate provides an overview of the certificates issued for this system.
Environmental conditions:	The calibration has been executed at a temperature between 22 °C and 24 °C, and a relative humidity level between 30 %rh and 60 %rh.
Period of calibration:	2023-06-20 until 2023-06-30
Results:	The results of the calibration are stated on pages 3 to 3 including the calibration measurement capabilities.
Uncertainty:	The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor of k = 2 which provides a confidence level of approximately 95 %. The standard uncertainty has been determined in accordance with EA–4/02.
Traceability:	The measurements have been executed using standards for which the traceability to (inter-)national standards has been demonstrated towards the RvA (Dutch Accreditation Council).
Date:	2023-07-04
Name:	M. Hetebrij
Function:	FIM-lab Technician
Signature:	Mark Hetebrij 2023.07.04 10:32:09 +02'00'

PO Box 153
8300 AD Emmeloord
The Netherlands
Telephone: +31(0)885114222
E-mail: emg-lab@nlr.nl
Internet: www.nlr.nl

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This certificate is issued provided that the RvA assumes any liability.

Fig. C1: Front page of the calibration report of Autolog3000 DA system Dyn8

Appendix D Calibration certificate of the load cells measuring the friction loads

This Appendix contains the calibration data of the two load cells that measure the horizontal friction loads. Of these two load cells only the “A” outputs have been used and calibrated.
This appendix only shows that part of the calibration certificate that is of concern for the friction tests.

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CALIBRATION
RvA K 042

NLR – Royal Netherlands Aerospace Centre
Laboratory of force calibration
Department Structures Testing and Evaluation

Calibration-certificate

Page 1 of 5

Certificate number : 2023-013

Applicant	:	Att. Mr. G.J. de Jong, department AVTH Netherlands Aerospace Centre, Voorsterweg 31 8316 PR Marknesse
Order number	:	2493279.1
Instrument	:	2 loadcells (5 klbs)
manufacturer	:	Interface
type	:	1210BF-5k-B and 1210BF
serial number	:	82774 A (and B) and 7581 A (and B)
Calibration method	:	Tension calibration with increasing load levels
Environmental conditions during calibration	:	Temp.: 20.2 °C – 20.6 °C ± 1 °C. HR: 47.5 % - 50.2 % ± 2 % HR
Date/period/location of calibration	:	24 April 2023 at the Netherlands Aerospace Centre, Voorsterweg 31 8316 PR, Marknesse
Results	:	See page 2 to 5 incl.
Uncertainty	:	The reported expanded uncertainty is based on the standard uncertainty of the measurement multiplied by a coverage factor *k*, such that the coverage probability corresponds to approximately 95 %. The standard uncertainty has been determined in accordance with EA-4/02. Uncertainty of the measurement: 0.5%.
Traceability		The measurements have been executed using standards for which the traceability to (inter)national standards has been demonstrated towards the Dutch Accreditation Council RvA.

date : 01-05-2023

name : G. Bos

function : Head of force calibration laboratory

signature



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8300 AD Emmeloord
The Netherlands
Telephone : + 31(0)885113113
E-mail : info@nlr.nl
Internet : www.nlr.nl

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Reproduction of the complete certificate is allowed. Parts of the certificate may only be reproduced with written approval of the calibration laboratory.

This certificate is issued provided that neither NLR nor the RvA assumes any liability.

Fig. D1: Calibration certificate of the load cells measuring the horizontal friction loads, page 1

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Calibration-certificate

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Certificate number : 2023-013

Calibration-results:

In table 1 and 2 incl. is:

F_a	=	Actual load in kN generated by the calibration machine, for traceability see NLR Certificate 2022-012 and 02T27TRE.NLR
1st, 2nd and 3rd	=	Measured output values of the amplifier presented in mV/V
Mean	=	Mean of the three measured output values 1st, 2nd and 3rd presented in mV/V
Sollwert	=	Calculated value of the output in mV/V, using the formula F = A + B * X
q	=	Deviation, the difference between Mean and Sollwert, expressed in % of Mean
b	=	Repeatability, the difference between the highest and lowest values of the output, expressed in % of Mean

The presented values are valid in a measurement range as in each individual table is presented. This means that the measurement results are related to a measurement range between the first and the last measurement value, excluding the zero values.
The formula F = A + B * X is applied using the first 0-value and all other measurement values, but excluding the last zero value.

For this calibration the loadcells were connected to a HBM Strain Gauge Amplifier MGCplus 1, calibrated by HBK. Calibration date: 27-06-2022.

In table 3 an overview is presented of files, environmental conditions, identification, data, (factory) specifications, traceability and measurement uncertainty.

Fig. D2: Calibration certificate of the load cells measuring the horizontal friction loads, page 2

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Calibration-certificate

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Certificate number : 2023-013

TABLE 1 5 Klbf INTERFACE LC SN7581A TENSION

Fa kN	1st mV/V	2nd mV/V	3rd mV/V	Mean mV/V	Sollwert mV/V	q %	b %
0.0000	0.00000	0.00000	0.00000	0.00000	0.00000	-	-
0.9977	0.18143	0.18161	0.18158	0.18154	0.18110	0.24	0.10
1.995	0.36296	0.36310	0.36314	0.36307	0.36308	-0.00	0.05
3.987	0.72605	0.72626	0.72630	0.72620	0.72658	-0.05	0.03
5.978	1.08928	1.08950	1.08951	1.08943	1.08990	-0.04	0.02
7.970	1.45261	1.45292	1.45288	1.45280	1.45340	-0.04	0.02
9.961	1.81601	1.81636	1.81632	1.81623	1.81671	-0.03	0.02
11.95	2.17944	2.17987	2.17983	2.17971	2.17966	0.00	0.02
13.95	2.54288	2.54338	2.54335	2.54320	2.54462	-0.06	0.02
15.94	2.90660	2.90690	2.90691	2.90680	2.90775	-0.03	0.01
17.93	3.27023	3.27072	3.27065	3.27053	3.27089	-0.01	0.01
19.92	3.63411	3.63445	3.63442	3.63433	3.63402	0.01	0.01
22.41	4.08902	4.08941	4.08923	4.08922	4.08839	0.02	0.01
24.90	4.54365	4.54414	4.54405	4.54395	4.54277	0.03	0.01
0.0000	-0.00014	0.00003	-0.00011	-0.00007	0.00000	-	-

Measurement file: 17T03TRE.NLR

As interpolation-function can be used:

F = A + B*X

A = 5.26834E-03
B = 5.48008E+00

CORR. COEFFICIENT = 1

The loadcell characteristic can be expressed by:

X = AI + BI*F

AI = -9.61893E-04
BI = 1.82479E-01

CORR. COEFFICIENT = 1

(where X is expressed in mV/V and F in kN)

Fig. D3: Calibration certificate of the load cells measuring the horizontal friction loads, page 3

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Laboratory of force calibration
Department Structures Testing and Evaluation

Calibration-certificate

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Certificate number : 2023-013

TABLE 2 5000 lbf INTERFACE LC SN82774A TENSION

Fa kN	1st mV/V	2nd mV/V	3rd mV/V	Mean mV/V	Sollwert mV/V	q %	b %
0.0000	0.00000	0.00000	0.00000	0.00000	0.00000	-	-
0.9977	0.18638	0.18631	0.18626	0.18632	0.18587	0.24	0.06
1.995	0.37261	0.37273	0.37263	0.37266	0.37285	-0.05	0.03
3.987	0.74562	0.74573	0.74551	0.74562	0.74631	-0.09	0.03
5.978	1.11889	1.11891	1.11873	1.11884	1.11959	-0.07	0.02
7.970	1.49238	1.49216	1.49207	1.49220	1.49305	-0.06	0.02
9.961	1.86580	1.86574	1.86555	1.86570	1.86633	-0.03	0.01
11.95	2.23949	2.23935	2.23911	2.23932	2.23923	0.00	0.02
13.95	2.61308	2.61290	2.61273	2.61290	2.61420	-0.05	0.01
15.94	2.98677	2.98645	2.98635	2.98652	2.98729	-0.03	0.01
17.93	3.36032	3.36024	3.36002	3.36019	3.36038	-0.01	0.01
19.92	3.73413	3.73388	3.73365	3.73389	3.73346	0.01	0.01
22.41	4.20134	4.20109	4.20080	4.20108	4.20029	0.02	0.01
24.90	4.66855	4.66824	4.66792	4.66824	4.66713	0.02	0.01
0.0000	0.00042	0.00016	0.00006	0.00021	0.00000	-	-

Measurement file: 17T01TRE.NLR

As interpolation-function can be used:

F = A + B*X

A = 6.27767E-03
B = 5.33384E+00

CORR. COEFFICIENT = 1

The loadcell characteristic can be expressed by:

X = AI + BI*F

AI = -1.17678E-03
BI = 1.87482E-01

CORR. COEFFICIENT = 1

(where X is expressed in mV/V and F in kN)

Fig. D4: Calibration certificate of the load cells measuring the horizontal friction loads, page 4

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Certificate number : 2023-013

TABLE 3 Overview of files, environmental conditions, identification, data, (factory) specifications, traceability and measurement uncertainty

Loadcell: Interface	Bridge A	Bridge A
Type	1210BF-5k-B	1210BF
ID	82774 A	7581 A
Range (kN)	1-25 Tension	1-25 Tension
Measurementfile	17T01TRE.NLR	17T03TRE.NLR
Date	24-04-2023	24-04-2023
Temp. (ºC)	20.2	20.3
0-offset (mV/V)	0.02441	-0.01247
Traceability (2022)	202-012	2022-012
Uncertainty (%)	0.5	0.5
Measured sensitivity		
kN per mV/V	5.33384E+00	5.48008E+00
mV/V per kN	1.87482E-01	1.82479E-01
Factory sensitivity		
mV/V/5 klbs	4.171	4.049

Fig. D5: Calibration certificate of the load cells measuring the horizontal friction loads, page 5

Appendix E Calibration of the pressure gauge

The pressure gauge used to measure the inflation pressure was calibrated by the Trescal company. The certificate is shown in this Appendix.

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CALIBRATION RvA K 018

CERTIFICATE OF CALIBRATION

2304-27915

Customer information

Client	: National Aerospace Laboratory - NLR
Contact	: L. Prikken
Address	: Voorsterweg 31 8316 PR Marknesse The Netherlands
Reference client	: OM-125-NOP
Reference Trescal	: 202323435/1

Instrument information

Make	: GE DRUCK
Type	: DPI 800P
Description	: Digital pressure indicator
Serial number	: 8000010819
Identification number	: THA00106/DPI800P
Range	: -1 .. 35 bar
Accuracy	: -

Date of calibration : 1 May 2023

Used method

P1-02-P.002 Calibration of digital pressure indicators
Digital pressure indicators are calibrated by direct comparison with a reference digital pressure indicator or a pressure balance.

Environmental conditions

During these measurements the following conditions were not exceeded:

Ambient temperature	: 21 °C ± 3 °C
Relative humidity	: 45%rh ± 20%rh

Used reference

The measurements have been executed using standards for which the traceability to (inter)national standards has been demonstrated towards the Dutch Accreditation Council (RvA).

HP0100	Pressure/Controller Calibrator	cert n° 220803862
HP0102	Pressure/Controller Calibrator	cert n° 220906529

Technician
Melissa Dollenkamp

Issue date 1 May 2023

Head of the laboratory
Luc Van Pelt

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Unless otherwise stated, the calibration was performed at the address mentioned in the footnote.

Trescal Hengelo bv | J. Schumpeterstraat 10 | 7559 SG Hengelo | Netherlands | Telephone + 31 74 240 81 61 | Email: info.benelux@trescal.com

Page 1 of 3

Fig. E1: Calibration certificate of the pressure gauge, page 1

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Note

The instrument is measured but not adjusted, so the results are both 'as found' as 'as left'.
Recommended recalibration date : 1 May 2024

-1 .. 1 mbar

Reference value	Instrument value	Difference	Uncertainty ±	Units
-970,0	-970,3	-0,3	0,4	mbar
-800,0	-800,2	-0,2	0,4	mbar
-600,0	-600,3	-0,3	0,4	mbar
-400,0	-400,1	-0,1	0,4	mbar
-200,0	-200,0	0,0	0,4	mbar
0,0	0,0	0,0	0,4	mbar
200,0	200,1	0,1	0,4	mbar
400,0	400,2	0,2	0,4	mbar
600,0	600,2	0,2	0,4	mbar
800,0	800,2	0,2	0,4	mbar
970,0	970,4	0,4	0,4	mbar
800,0	800,3	0,3	0,4	mbar
600,0	600,3	0,3	0,4	mbar
400,0	400,3	0,3	0,4	mbar
200,0	200,2	0,2	0,4	mbar
0,0	0,0	0,0	0,4	mbar
-200,0	-200,1	-0,1	0,4	mbar
-400,0	-400,2	-0,2	0,4	mbar
-600,0	-600,2	-0,2	0,4	mbar
-800,0	-800,3	-0,3	0,4	mbar
-970,0	-970,3	-0,3	0,4	mbar

1 mbar = 0,1 kPa

0 .. 35 bar

Reference value	Instrument value	Difference	Uncertainty ±	Units
0,000	0,000	0,000	0,012	bar
7,000	6,998	-0,002	0,012	bar
14,000	13,997	-0,003	0,012	bar
21,000	20,996	-0,004	0,012	bar
28,000	27,996	-0,004	0,012	bar
35,000	34,996	-0,004	0,012	bar
28,000	27,996	-0,004	0,012	bar
21,000	20,995	-0,005	0,012	bar
14,000	13,996	-0,004	0,012	bar
7,000	6,997	-0,003	0,012	bar
0,000	0,000	0,000	0,012	bar

1 bar = 100 kPa

Difference = Instrument value - Reference value.

Pass/Fail tests and visual inspections are not covered by the ISO/IEC 17025 accreditation scope.

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Fig. E2: Calibration certificate of the pressure gauge, page 2

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CERTIFICATE OF CALIBRATION

2304-27915

The stated uncertainty is that of the entire set-up including the object under test.
The reported expanded uncertainty is based on the standard uncertainty of the measurement multiplied by a coverage factor k, such that the coverage probability corresponds to approximately 95%.
The uncertainty is calculated according to EA-4/02.

END of CERTIFICATE

Pass/Fail tests and visual inspections are not covered by the ISO/IEC 17025 accreditation scope.

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Fig. E3: Calibration certificate of the pressure gauge, page 3

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Royal NLR - Netherlands Aerospace Centre

NLR operates as an objective and independent research centre, working with its partners towards a better world tomorrow. As part of that, NLR offers innovative solutions and technical expertise, creating a strong competitive position for the commercial sector.

NLR has been a centre of expertise for over a century now, with a deep-seated desire to keep innovating. It is an organisation that works to achieve sustainable, safe, efficient and effective aerospace operations.
The combination of in-depth insights into customers' needs, multidisciplinary expertise and state-of-the-art research facilities makes rapid innovation possible. Both domestically and abroad, NLR plays a pivotal role between science, the commercial sector and governmental authorities, bridging the gap between fundamental research and practical applications. Additionally, NLR is one of the large technological institutes (GTIs) that have been collaborating over a decade in the Netherlands on applied research united in the TO2 federation.

From its main offices in Amsterdam and Marknesse plus two satellite offices, NLR helps to create a safe and sustainable society. It works with partners on numerous programmes in both civil aviation and defence, including work on complex composite structures for commercial aircraft and on goal-oriented use of the F-35 fighter. Additionally, NLR helps to achieve both Dutch and European goals and climate objectives in line with the Luchtvaartnota (Aviation Policy Document), the European Green Deal and Flightpath 2050, and by participating in programs such as Clean Sky and SESAR.

For more information visit: **www.nlr.org**

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