German-Dutch Wind Tunnels

Mechanical requirements of wind tunnel models to be tested in LLF/LST

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SUMMARY

This document is the result of a study on safety factors for DNW wind tunnels. For this an inventory and comparison of existing safety factors and design rules of a number of other wind tunnels have been made.

In this document presents the mechanical requirements of wind tunnel models to be tested in DNW-LLF/LST.

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ABBREVATIONS

CE	Conformité Européenne
DNW	Duits–Nederlandse Windtunnels (German Dutch Wind Tunnels)
EMC	ElectroMagnetic Compatibility
FEM	Finite Element Method
LLF	Large Low speed Facility
LST	Low Speed Tunnel
SF	Safety Factor
σ_{ult}	Ultimate Tensile Strength of material
σ_{yield}	Yield Strength of material

1 INTRODUCTION

This document is the result of a study on safety factors for DNW wind tunnels. For this an inventory and comparison of existing safety factors and design rules of a number of other wind tunnels have been made.
The text can readily adapted for other DNW wind tunnels.

1.1 General philosophy

In this document general guide lines are given for design of wind tunnel models and/or auxiliary equipment to be used for specific wind tunnel tests at DNW-LLF. The general guide lines also include minimum safety factors with which designs have to comply.
Complying with all criteria given in this document does not imply a shared responsibility with respect to safe and proper functioning of customer's model and/or auxiliary equipment in DNW wind tunnels. The customer will remain responsible for the safe and proper functioning of its model and/or auxiliary equipment at all times, unless otherwise agreed in writing with DNW.
The given general guide lines for design and minimum safety factors are applicable to new and existing models and/or auxiliary equipment to be used at DNW-LLF/LST. Existing parts which are modified should also comply with these rules and the results should be documented.
Furthermore, DNW shall have the right to request additional analyses if deemed necessary to comply with said guide lines.

All required documentation should be available to DNW ultimately three weeks prior to the wind tunnel test, although it is recommended to send it as soon as possible; in this way possible advantageous recommendations from DNW can still be incorporated.

2 DESIGN RULES & APPLICABLE SAFETY FACTORS

1.2 Design Information

2.1.1. Design Loads

The overall model loads and loads on individual model parts and/or sub-assemblies are to be indicated.
All foreseen model configurations during testing, and all tunnel environment settings (wind speed, angles of incidence, yaw and roll, pressure, temperature) should be taken into account in the load analysis.

An analysis of the several types of expected loads should be given :

- (Quasi) static aerodynamic loads including location of aerodynamic centre
- Expected dynamic allowance on aerodynamic loads
- Temperature induced loads
- Gravitational loads
- Inertia loads (e.g. moving parts)
- Friction loads
- Loads due to rotation (unbalances, gyroscopic, centrifugal)
- Pressure
- Any other relevant load

For each calculation it should be indicated how the worst case load combination has been derived from above listed type of loads, together with possible influential factors (e.g. used friction coefficients, used gravitational constant).
If alternating loads are expected a fatigue analysis is required.

2.1.2. Determination of Critical Model Parts

It should be clearly indicated which model parts are assumed to be critical, and therefore require a stress analysis, and/or fatigue analysis and/or fracture analysis.
If a limited fatigue life is expected for certain parts, a thorough fatigue analysis is required. Also a system for life cycle monitoring (incl. recorded history in case of existing parts) is required.

The critical model parts including the critical cross sections should be clearly indicated in drawings or sketches.

If failure of critical parts could lead to loss of the model or model parts, and therefore could damage the tunnel facility, and/or unforeseen unfavourable conditions occur during testing which yield to higher safety risks, DNW will have the right to impose specific higher safety margins.

2.1.3. Calculation Methods to be used

The calculation methods that will be used for stress assessment shall be clearly indicated. Only well-proven and well-documented methods should be used, in order to facilitate an easy check on validity of the applied methods. References to the original method sources should be added.
If equations are used, the describing general formulas should also be given.

Multi-axial stresses may combined using combined stress theorems (e.g. von Mises), and used for calculating the safety margin.
If stress concentration effects are analysed, this should be done for the combined and the principle stresses (the maximum value and location could differ for the two). In case of Handbook analysis, references to original sources (e.g. Peterson's Stress Concentration factors) are to be given.

For each calculated part the following information should be given :

- A simple drawing with main relevant dimensions and loads application
- Simplification of the load case and boundary constraints
- Any assumptions and/or approximations used for the calculations
- Material specification (ultimate - and yield strength, fatigue strength)
- Applicable general formulas before numerical input
- Analysis of the calculated total stress
- Factor of Safety check

If Finite Elements Methods are use for calculations, the applied FEM program should be indicated, together with the used modelling strategy and element choice. It should be demonstrated that the used FEM program is well-known and well-suited for this type of calculation. Handbook calculations should support the general validity of the FEM results.
For each FEM calculation the following information should be given :

- Element types, size and numbers.
- Used element properties
- Boundary Constraints
- Any assumptions and/or approximations used for the calculations
- Applied load(s)

- Analysed maximum stress (combined stress, stress concentration and location)
- Analysed deflection
- Stress plots of the calculated part

Also for other computerised calculation methods (e.g. FlightLab for calculating helicopter loads, or composite structures calculations), the validity and applicability for this particular goal should be demonstrated.

DNW will have the right to request additional analyses of parts/cross sections, if deemed necessary.

2.1.4. Material Selection and Intended Use

All relevant properties (mechanical, thermal and physical properties) of the selected materials should be given. If taken from recognized standard material property data sheets, the minimum properties should be used for stress calculations. Any special condition (e.g. heat treatment) should be indicated and the appropriate minimum values should be chosen.
For materials without standard property data sheet, dedicated test results which demonstrate the applicability of the chosen material must be added.
Materials with certain unknown relevant properties (e.g. composites) should not be used for critical parts without a documented positive test result (loads, vibration, temperature, deflection etc.) of the actual model part. Basic material properties should be determined experimentally on test specimen. It is recommended to inform DNW at the earliest possible stage on the foreseen use of such materials and already indicate the chosen material test strategy, in order to have a mutual agreement on this before manufacturing the model parts.
The main structure of the model may only be constructed of a non-metallic (e.g. composites, wood etc.) material with prior approval of DNW.

If materials are prone to aging with deteriorating properties, the period of applicability should be clearly indicated. These materials should not be used for critical parts.

Materials which are used for non-structural elements (e.g. filler materials, sealing material, insulating materials) should be clearly indicated and analysed for possible failure. Material properties and handling instructions should be provided.

Materials that require special handling instructions due to hazardous nature can not be applied without explicit approval of DNW.
Any flammable medium can not be used without prior approval of DNW.

2.2 Stress & Strength Assessment

If the expected dynamic allowance on the aerodynamic loads exceeds 20% of the maximum static loads, this should be taken into account in the stress analysis. Any assumption that the allowance is less than 20%, should be made plausible by calculations and/or experiences/results with comparable situations.

2.2.1. Overall Stresses

<u>Metallic Parts</u>

In case of Handbook analysis :
The calculated combined stress should not exceed **25% (1/4, SF = 4)** of the material's ultimate tensile strength. The combined stress should comprise all effects as a result of tension/compression, bending, shear, stress concentration, centrifugal, temperature and pressure.
In case of mainly shear, the calculated shear stress should not exceed **17% (1/6, SF=6)** of the material yield stress, or **25% (1/4, SF=4)** of the material's ultimate shear stress, whichever is lower.
The calculated buckling stress should not exceed **33% (1/3, SF=3)** of the critical buckling stress.
The calculated contact pressure should not exceed **67% (2/3, SF=1.5)** of the maximum allowable contact pressure (material property).

In case of FEM analysis :
The calculated combined stress should not exceed **40% (2/5, SF=2.5)** of the material's ultimate tensile strength. The combined stress should comprise all effects as a result of tension/compression, bending, shear, stress concentration, centrifugal, temperature and pressure.
In case of mainly shear, the calculated shear stress should not exceed **33% (1/3, SF=3)** of the material yield stress, or **50% (1/2, SF=2)** of the material's ultimate shear stress, whichever is lower.
The calculated buckling stress should not exceed **50% (1/2, SF=2)** of the critical buckling stress.
The calculated contact pressure should not exceed **67% (2/3, SF=1.5)** of the maximum allowable contact pressure (material property).

<u>Non-metallic Parts</u>

Non-metallic materials should preferably not be used for critical parts (to be agreed with DNW).

The calculated combined stress should not exceed **25% (1/4, SF = 4)** of the material's ultimate tensile strength, OR the material's Fatigue Endurance Limit stress, whichever is lower. The combined stress should comprise all effects as a result of tension/compression, bending, shear, stress concentration, temperature and pressure.
The calculated shear stress should not exceed **33% (1/3, SF=3)** of the material's ultimate shear strength, for both interlaminar and transverse directions.

In the documentation it should clearly be indicated that the used calculation methods for non-metallic parts are adequate and valid for this specific application.

Structural Joints & Welds

Threaded parts (bolts) and welded joints are widely used in model design.
All loads including shear should be transferred by pre-stressed or shape-closed joint systems. The use of keys, shoulder pins etc. should be preferred; for the stress analysis the contribution of friction loads should be neglected.

Threaded Parts

The total stress in threaded parts may not exceed 70% of the yield strength of the bolt material. The calculation of the stresses in threaded parts should include all effects of external loads, flange stiffness and stresses due to torque moments. Calculation methods should be consistent with international standards such as EN-1660, EN-1591, EN-13480 and EN-13445. The used standard for bolt calculations should be indicated in the documentation.
Bolt joints should be sufficiently pre-stressed to avoid flange separation under 1.5 times maximum load.
The assembly must be able to withstand the loss of the highest loaded bolt as defined by the analysis.
Joints must be locked mechanically if subject to vibration (use tab washers or locking wire).
Use thread inserts in light alloys and composites. Note that stress and strength analyses are required for these inserts also.
Screw thread engagements should be demonstrably sufficient with respect to length.
Use preferably cylinder head screws in stead of countersunk screws, especially for critical connections.

Welded Joints

The stresses in welded joints due to the loads have to be analysed. Considerations to relieve stress in the welded joint have to be made, the goal should be to minimise the residual stresses.
Welding specifications have to be documented, including the welding plan.

In case of pressure vessels and or pressure lines the design, material selection, qualification of the welder, leakage tests, etc should be conform CE-regulations.

Glued Joints

Glued joints are only permitted in case of low loaded parts which in case of failure will not separate from the model. The use of glue has to be discussed with DNW.

2.2.2. Pressurised Systems

All pressurised systems (compressed air or other gas, hydraulic systems) have to be designed, manufactured and delivered in accordance with CE-marking.
At least the following three tests have to be performed and documented :

1. Parts pressure tests : parts (or logical sub-assemblies) have to be pressurised to **1.3 x working pressure + 2 bar**, and kept on this pressure for at least **30** minutes. After the test structural integrity may not be compromised and no deformation of parts should have occurred.
2. Leakage test : on pre-assembled subsystems which will be delivered as a unit and without disassembling be mounted in the model at DNW. The leak test should be done with a pressure between **6** and **12** bar (or the working pressure if lower) for at least **30** minutes. No leakage should occur.
3. Total system pressure test : in principle on the total system as to be used during the wind tunnel test. If not possible, prior agreement with DNW should be reached on how to demonstrate the leak-free and save functioning of the system. For this test the pressure should be slowly increased to **1.1 x the working pressure**, and after reaching this maximum value the system should be depressurised at once. After the test structural integrity may not be compromised, no deformation of parts should have occurred and no leakage may have occurred.

Any necessary auxiliary parts to perform these tests should be delivered with the system.

2.2.3. Moving mechanisms and rotating systems

Mechanical devices formally to be indicated as Machines (e.g. Remote controls) have to be designed, manufactured and delivered in accordance with CE-marking.

Rotating systems should be balanced to avoid vibrations. A specified Balance Quality Grade according to ISO 1940/1 must be realised. Dangerous operating conditions (e.g. unfavourable Eigen frequencies) discovered during the design have to be identified (e.g. with a Campbell diagram analysis) and have to be discussed with DNW.

To recognize any potential hazardous condition (vibration levels), control circuits for basic monitoring have to be built in the system. It is strongly recommended to consult DNW in an early stage of the design in order to avoid additional required activities by customer during mounting of the installation in the wind tunnel.

A detailed fatigue analysis using a modified Goodman diagram is required for any rotating system. Blades to be used in rotating systems should be subject of extra tests before the approved use in the wind tunnel. After the production every blade should be subject of static tests and Eigen-frequency tests.

In case of moving systems like remotely controlled surfaces, mechanical safety stops should be present in order to avoid possible loss of model parts in case the electrical control system fails. Control systems of moving mechanisms should have runaway safety provisions.

2.3 Electrical Equipment & Components

All electrical equipment and components which are to be used in the wind tunnel should be demonstrably fit for use. If special equipment or facilities are necessary (e.g. high voltage, strong currents) for exciting the electrical components, DNW should be consulted in prior.
Adequate EMC shielding should be demonstrated.
If telemetry systems are foreseen, DNW should be consulted in prior.
Control systems of moving mechanisms should have runaway safety provisions.

2.4 Handling & Storage

All parts heavier than **23 kg** should have hoisting provisions in order to make safe handling possible. Any necessary special hoisting or handling instructions should be clearly indicated in the accompanying documentation. Any special devices should be delivered with the model.
All parts and storage crates shall have a unique identification.
All crates heavier than **46 kg** shall have provisions for easy transportation, e.g. wheels or enough ground clearance for using forklifts.
The total assembled model weight should not exceed **1500 kg**. The location of the centre of gravity should be clearly indicated on the drawings or in the accompanying documentation.

3 REQUIRED DOCUMENTATION

With the model the following documentation should be delivered :

- Stress Analysis Report including material data sheets and certificates
- Set of as-built drawings
- Inspection report including dimensions of critical parts
- Handling & User Manual (amongst others containing assembly notes and prescribed torque moments)
- Any other information necessary to evaluate the compliance with DNW's safety and health requirements as given in this document.

Appendix A Check List/Overview

§2.1.1	**Design Loads**			
		Applicable worst case load combination	Include all relevant contributions	
		Dynamic allowance > 20%	Include in stress analysis	
		Alternating loads expected	Include fatigue analysis	
§2.1.2	**Critical Model parts/ sections**			
		Include Free body diagram		
		Limited fatigue life expected	Include fatigue analysis	System for life cycle monitoring required
§2.1.3	**Calculation methods**			
		Handbook analysis	Reference to original handbook sources	
		FE Methods	Demonstrate validity of results with handbook calculations	
		Other methods	Demonstrate validity and applicability for particular goal	
		Stress concentration effects	Reference to original handbook sources	
			With FEM check max. Value and location for both combined and principle stresses	
§2.1.4	**Material Selection and Intended Use**			
		Relevant Material properties	Existing data sheet ⇒	Use Minimum properties
			No data sheet ⇒	Dedicated test results necessary for determining minimum properties

		Main structure Non-metallic	Only with prior approval of DNW			
§2.2	**Stress & Strength**					
§2.2.1	**Metallic parts**					
			Handbook analysis ⇓	**FE Methods** ⇓		
		Combined stress	SF = 4 on σ_{ult}	SF = 2.5 on σ_{ult}		
		Mainly shear stress	SF = 6 on σ_{yield} OR SF = 4 on Ultimate shear stress whichever is lower	SF = 3 on σ_{yield} OR SF = 2 on Ultimate shear stress whichever is lower		
		Buckling stress	SF = 3 on critical buckling stress	SF = 2 on critical buckling stress		
		Contact pressure	SF = 1.5 on allowable material contact pressure	SF = 1.5 on allowable material contact pressure		
§2.2.1	**Non-metallic parts**					
		Combined stress	SF = 4 on σ_{ult} OR materials Fatigue Endurance Limit stress whichever is lower			
		Shear stress	SF = 3 on Ultimate shear stress for both			

			interlaminar and transverse directions		
§2.2.1	**Threaded parts**	Maximum allowable stress < 70% of σ_{yield}	Joint able to withstand loss of highest loaded bolt	Should be locked if subject to vibration	Apply inserts in light alloys and composites; stress analysis also required for inserts
§2.2.1	**Welded joints**	Analysis of residual stresses	Welding specifications to be documented	In pressurised systems conform CE	
§2.2.1	**Glued joints**	Only for low loaded parts	To be discussed with DNW		
§2.2.2	**Pressurised systems**	Designed in accordance with CE	Part test : **1.3 x working pressure + 2 bar**, for at least **30** minutes.	Leak test : pressure between **6** and **12** bar for at least **30** minutes	Total system check : slowly increase to **1.1 x the working pressure**, and depressurise at once
§2.2.3	**Moving mechanisms & rotating systems**	Designed in accordance with CE			
		Rotating Systems	Rotating systems to be balanced acc. to ISO 1940/1	Operating conditions to be analysed (Campbell diagram)	Detailed fatigue analysis with a modified Goodman diagram required for rotating systems
		Moving Mechanisms	Mechanical safety stops required	Control system should have runaway safety provisions	

§2.4	**Handling & Storage**					
		Total weight of assembled model should be < 1500 kg	If parts > 23 kg then hoisting provisions necessary	Crates > 46 kg provisions for easy transportation necessary		