RULES FOR THE DESIGN OF WIND-TUNNEL MODELS, SET-UPS AND TEST RIGS

HISTORIQUE

Update version	Implementation date	Cause et/ou nature de l'évolution
2.1	December 2019	Details with respect to mechanical sizing of 3D printed parts. Modification of the sizing criterion for metallic parts submitted to traction, compression, bending and torsion
2.0	June 2018	Major updating and extension to the design of set-ups and test rigs.
1.1	October 2013	Modification of Appendix A (F1 Pressure tape tubing interface).
1.0	December 2012	New identification GMT - Add specifications concerning §6.2.5 and new appendix B.
4.0	May 2010	Major updating.
3.0	June 2007	Addition of instructions (§7.2) concerning the specifications for the flexible pipes of pressure taps (following to the progress index DCBE/02/10) and translation update.
2.0	August 2001	Update with the new organisation of GMT and according to the new procedure forms. Cancel and replace the procedure: AQ/GME.G.04/PT/001.
1.0	March 1997	Creation.

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SOMMAIRE

1 AIM

The aim of this procedure is to give the main rules to be respected for the design of aerodynamic wind tunnel models, set-ups and test rigs. This procedure cannot cover all the technologies likely to be used but it constitutes a manual for the most common ones.

In order to lighten the text of the present procedure, the generic term "Test Device" is used below replacing the set of "models, set-ups and test rigs".

2 APPLICATION FIELD

This procedure applies to the various Design Offices (ONERA, customers and their suppliers) that are in charge of Test Device design/manufacturing intended to be tested in ONERA/DS facilities.

Furthermore, the designers can, on simple request, take benefit from ONERA/DS (Design Office and/or wind tunnel staff) experience during design reviews.

3 APPLICABLE AND REFERENCE DOCUMENTS

The Test Device must be designed in accordance with European Safety Regulations (Directive Machines, DESP, ATEX, Electrical standards…) if these rules are required.

4 DEFINITIONS

- Design : all the activities consisting in transforming the functional requirement and the performances asked by a customer with feasible technical solutions including the associated control and verification specifications.

- Test field : definition of the use conditions and limits of the model according to the available test means; it mainly includes :

  - Aerodynamic field: Mach, stagnation pressure and stagnation temperature of the wind tunnel and if applicable the particular conditions (ice, hygrometry, etc…);

  - Attitudes: incidence, sideslip, roll and the particular conditions (dropping, turning activation, etc…);

  - Ancillaries: extraction (flow, pressure) for air entry, compressed air (flow, pressure, temperature) for nozzle or turbine;

- Loads : aerodynamic related strains and moments, or others (centrifugal, inertial, thermal…), the model undergoes on the entire test field..

5 DESIGN FILE

The design file for a test device must contain the following elements:

- The test field and the corresponding loads which constitute the entry data of the design and which allow to establish drawings and stress reports.

- The stress report that justify the geometry, the dimensions, the assemblies and the choice of materials and components in function of the strains (mechanical, aeraulic, thermal) and deformations of the model **“to be provided to ONERA not later than 1 month before the**

start of a test in order to allow the verification of its conformity with the present procedure";

- The drawing package includes:
  - the assembly drawings which must provide the following information (especially in the case of a model):
    ⇒ the customer references, the fuselage horizontal reference (FHR)
    ⇒ the moment reduction centre
    ⇒ the balance centre
    ⇒ the hinge and balance axis position for measurement of the hinge moments, and also the positions of load application points;
  - the subassembly and detail drawings for the manufacturing and assembly of the various configurations of the device, whenever appropriate;
  - the manufacturing tolerance and the surfaces roughness;
- The description of the screws specifying in particular for each assembly the type of screw and the tightening torques to be applied;
- The control and test requirements, in the case of geometric inspections, mechanical tests and/or hydrostatic tests;
- The definition of the equipment (instrumentation, sensors, motors), with associated connectors and cabling;
- The assembly and handling instructions;
- The complete nomenclature including off-the-shelf components;
- The description of the materials used specifying the references as well as the heat treatment and surface treatment specifications ;
- The 3D modeling of the test device in a format to be defined in agreement with the Test Manager;

Anyway, the designer has to give all the necessary information before each design review. These reviews have to be organised with participation of the ONERA/DS staff (Facility and Test Managers, Design Offices…).

The design file will be provided on CDROM, by transfer by file exchange server in PDF format or possibly in the form of paper documents.

In the case of files subject to specific privacy statements (DR, CD), the procedures for providing the corresponding data will be implemented.

6 STRESS REPORT

6.1 TEST ENVELOPE AND LOADS

6.1.1 General rules

All the aerodynamic loads acting on the Test Device, considered as a whole and on all sub-assemblies and individual parts constituting it, are provided by the customer for all the configurations to be tested and the extreme values of the test domain. The stresses generated by other loads, either primary ones (induced by gravity, limit conditions…) or secondary ones (induced by thermal gradients) have to be determined by the designer. Finally, the potential fatigue analysis has to be carried out by the designer. The extreme values of the test field must be validated by the wind tunnel staff to take into account the specificities of the facility.

The various stresses, in particular those related to gravity, aerodynamics, thermal stresses, inertia (mobile subsets or dynamic effects), unbalance and gyroscopic effects for the rotating parts, must be explicitly mentioned as well as the justification of the cases considered for sizing.

Some cases of failure (for example: loss of blades) must be specifically justified with respect to the selected hypothesis. The chosen approach, in case of loss in the wind tunnel of elements of significant size, must be discussed with the Test Manager, the Facility Manager and the Design Offices of ONERA/DS. Similarly, if one or more fuse elements are integrated into a test device, their strength must be the object of a detailed justification after agreement of the Test Manager, the Installation Manager and ONERA/DS Design Offices on the proposed configuration.

All surfaces sensitive to aerodynamic effects but normally to the incidence of zero lift will be assumed to have a misalignment of $\pm$ 1 °.

The conventions of signs (deflections of elements, model reference, loads) are to be provided by the customer.

Note: the scale chosen for the Test Device must systematically take into account the constraints of the wind tunnel, especially from the point of view of test section obstruction and wall corrections.

6.1.2 Dynamics loads

If the dynamic part of the forces that the Test Device will be submitted to is not known during the design phase, the corresponding stresses are estimated from static stresses. Except for some of the cases listed below, **the dynamic part will be considered as equal to 20% of the static forces**.

For the following cases, the dynamic part to consider is larger:

- Hinged surfaces (aileron, rudder, ...): **30%**
- Missile with angle of attack greater than 30 °: **40%**
- Elements such as trap doors, landing gears, stores: **100%**
- Surfaces with very unsteady flow (spoilers, slotted flaps, slats, ...): **100%**
- Airplane with risk of buffeting: **300% on X, 20% on the other components**

In case the designer of a test device wishes to have confirmation of the level of dynamics to be considered for the sizing, he has to get in touch with either the test manager or one of the ONERA / DS design offices.

6.2 CHOICE OF MATERIALS

The choice of materials is justified according to the characteristics resulting from official standards or from test results (Test Report to be provided). In the case of a newly manufactured Test Device, the material certificates for the various parts constituting it are to be provided (for example in the form of appendices to the calculation note).

Depending on the intended use, the retained mechanical characteristics are to be indicated. The designer will specify the domain of validity: the conditions of use (temperature, environment), the characteristics at delivery (type of the raw material), the characteristics of treatment (metallic materials) or of manufacturing (composites).

Special attention must be paid to the strength and deformation of the models subjected to high temperatures during tests on specialized installations (for example: BD2MA, CEPRA19- need to adapt assembly tolerances on hot parts to avoid jamming).

6.3 VALIDATION OF THE MECHANICAL STRENGHT

6.3.1 General rules

For each calculated element, the designer will give the characteristics of the material and the numbers of the corresponding drawings. He will describe the used input data and the selected hypothesis.

In the case of an analytical calculation, a diagram should be provided including the dimensions, the used sections and inertia, the vector representation of the forces, the simplifying hypothesis. To justify the choice of the critical section of a calculation, the designer has to clearly present, for each type of stress taken separately then for the combined stresses (traction, compression, bending, torsion, shear...), the place where the stresses are maximum. The calculation of the stresses includes the concentration coefficients (static and dynamic), the surface conditions coefficients as well as scale factor coefficients (dynamic). The values selected for these coefficients have to be clearly indicated.

In the case of using a finite element software, the name of the software and the way of modelling are indicated. The designer will describe the chosen mesh (type and number of elements), the boundary conditions and the selected hypothesis.

For complex structures, the coefficients of influence for defining the stress resulting from the various cases of combined forces to be taken into account will appear at various significant nodes of the mesh.

For any calculation, the equations, when used alone, must be in literal form before the introduction of numerical values.

6.3.2 Validation of the parts holding

a) General rules

Apart from any more restrictive specification, the following calculation codes should be followed: ANSI, AISC, ASTM, AWS, ASNT, NEC, NDSSGL, SAE, LHB, NBS. The French regulations are fully applicable to the Test Devices at the date of the tests.

b) Metallic materials (excluding screws)

- Traction / Compression / Bending / Twisting :

In the case of **nominal loads**, the combined stresses should be **less than the lowest value of**:

- **75% of the Yield Tensile Stress (YTS),**
- **50% of the Ultimate Tensile Stress (UTS)**.

In the case of exceptional stresses (failure, breakage of a blade on a rotating device for example), it should be ensured that there will be no plastification. In such a configuration, the combined stresses must remain **below 95% of the YTS**.

- Buckling :

  The buckling stress will be **less than 50% of the critical stress.**

- Pure shear :

  The shear stress will be **less than 33% of the YTS.**

- Contact pressure :

  The contact pressure will be **less than 67% of the allowable pressure**

Depending on the used materials, it may be difficult to access the value of the maximum contact pressure (or matting pressure). For steels of UTS > 900 MPa, the maximum contact pressure can be considered as YTS. For steels with lower characteristics, the percentage of carbon must be taken into account. For aluminum alloys, the value to be retained is ½ YTS. It is recalled that this approach is valid for static contact pressures and not shocks.

c) Polymers

Except for specific cases that would have to be thoroughly justified, ONERA does not recommend the use of polymer materials for structural elements.

In all cases, the limits of considered stresses must be justified by the designer depending on the used material (thermoplastic, thermosetting, ½ crystalline, amorphous...) and conditions of use (temperature, hygrometry, frequency).

d) Arts made by additive manufacturing

The stress limit values are those applied to metallic or polymeric materials depending on the used material.

The designer/manufacturer of such parts must ensure, for example thanks to specific tests on specimens, the actual mechanical characteristics of the material generated by additive manufacturing. The specimens must be manufactured on the same machine, using the same powder, according to the same manufacturing process (direction of part building) as the considered parts. The directions of the main loads to be applied should be the same.

In the case of parts potentially submitted to significant dynamic loads, the designer/manufacturer will ensure thanks to fatigue tests on specimens the maximal acceptable stress level for an infinite lifetime of the material.

In the case where the designer/manufacturer already has available an experimental database established to fully qualify such a manufacturing process, he will have to demonstrate that all the parts obtained by additive manufacturing and planned for a specific application are generated in conditions addressed in the database. If it is not the case, the designer/manufacturer will have to ensure thanks to additional tests that the modifications are without any impact on the final mechanical characteristics of the parts.

e) Composite materials

To check the static behavior of the parts, the designer will rely on a damage criterion to be specified (Tsai Wu, Tsai Hill, Yamada Sun...). However, except for specific cases that would have to be thoroughly justified, ONERA does not recommend the use of composite materials for structural elements.

f) Filing materials

The used materials must have been approved by ONERA after communication of the intended conditions of use (bonding, thickness, mass...) and possibly communication of the main properties.

g) Elements submitted to pressure (air, gas), i.e. ESP

- <u>Standards and regulations :</u>

Equipment subject to a maximum allowable pressure (PS) of more than 0.5 bar falls within the scope of PED 2014/68 / EU. Risk categories I to III must meet the essential safety requirements of the PED and thus the transposition decree N° 2015-799 dated of 1 July 2015. ESP falling within the frame of Article 4.3 of this Directive might not meet these essential safety requirements.

Appendix I defines the design criteria to be fulfilled.

All new equipment from Category I and above must be CE marked (in Category I the manufacturer is self-certifying). The scope of this marking may also cover electrical aspects, Machinery Directive ... This scope must be specified in the "EC Declaration of Conformity" associated with the equipment subjected to pressure.

The reference building codes will preferably be the CODAP for a tank, the CODETI for a pipe, the CODAP or the CODETI for accessories. Experience shows that generally a model, a set-up or a test rig are in the piping category.

For risk categories I to III, materials used for pressure equipment shall comply with the Directive (Appendix I, paragraph 7.5) with respect to elongation and resilience.

Specific tests on test specimens may thus be required if these values are not guaranteed by a harmonized standard of supply. Special attention should be paid to the required certificates (type 3.1).

Similarly, the hardware for the fasteners must comply with the criteria of the Directive. The use of such materials as 30CND8, 42 CrMo4 will be favored. The 8.8 class screws cannot be selected for a primary use but only for troubleshooting (subject to a request for an exemption). The harmonized standard NF EN 10269 of December 2013 (steels and nickel alloys for fasteners used at high temperature and / or low temperature) lists the materials that can be used along with their mechanical characteristics at ambient or high temperatures, elongation, etc.

Note: In the case of pressure equipment supplied by a non-EC customer, the latter must provide at least the documents required for Category I (see Annex I of the Directive), even if the regulations in force in the country of origin do not require them.

APAVE assistance may be requested by the test manager from the customer who designs / manufactures equipment submitted to pressure. In this case, this request will be made from the beginning of the project.

- Operation domain :
  During the design phase, the definition of the calculation and / or operation limits associated with the presence of safety devices (valve, pressure switch, etc.) and the possible integration into an existing network must be validated in accordance with the testing and / or installation manager (See Appendix C).

- Tests :
  Any equipment submitted to pressure must undergo a hydrostatic test before being commissioned in a wind tunnel. This test must be performed by relying for example on the rules of CODETI (liquid, pressure, pressure stages ...). All hardware (plugs, screws, etc.) specific to the performance of this test must be supplied together with the equipment submitted to pressure so that they can be used for sealing tests prior to commissioning in the wind tunnel.

  Following this test, the equipment submitted to pressure must be marked in accordance with the recommendations of the Directive.

- Deliverables:
  For all equipment submitted to pressure, an assembly drawing as well as a list of fasteners and seals and a summary table of tightening torques must be provided. As much as possible, the detail drawings of the parts will show the following indications: nature of the fluid, type of fluid (for operation or for the hydrostatic test), PS, TS, V, DN.

- Existing equipment :

In the case of a Test Device that has already been tested in a wind tunnel in the past, a case-by-case risk analysis must be conducted. This analysis may trigger compensatory measures.

h) Fatigue

To validate the fatigue life of parts, the alternate peak and average stresses will be considered in a diagram of Haigh, Goodman or equivalent.

Wöhler curves specific to the material under consideration can be used, either extracted from literature or by mathematical construction.

In the case of parts made by additive manufacturing, particular attention will be paid to the method of determination of the equivalent dynamic stress (tests on following specimens, certificates…).

6.3.3 Validation of mechanical connections

a) General remarks

By default, all efforts must be transmitted by positive means (keys, pins, shoulders...). Tackling efforts by friction alone can be considered only under some conditions specified below.

The assembly screws of a Test Device should not be submitted to shear stresses.

b) Screwed connections

- Stress calculation :

The sizing of the screws will be done considering the static forces increased by known dynamic coefficients or as defined in §6.1. The assembly must be designed to cope with the absence of the most loaded screw, as defined by calculation.

The stress in the screws must not exceed 80% of YTS. Bolted connections must be prestressed to a maximum of 70% of YTS to avoid separation under loads. Note that UTS= 1400 MPa should not be exceeded in the screws.

In order to limit tightening torque calculations, a standard table can be used (see Appendix 2). The tightening torques given in this table correspond to the calculated torques for a stress in the screw equal to 50% of YTS.

If the applied force is greater than that indicated in the standard table, the tightening torque of the fasteners is defined using the NBS, CETIM or equivalent calculation method, taking into account the rigidity ratios of the assembly and the torsion stress when tightening.

The type of used lubrication is to be mentioned explicitly along with the tightening torques.

- Technical choices :

For screws of a diameter of M3 or lower, the use of a Torx head is strongly recommended to avoid damage to them when applying tightening torques. A Philips / Pozidriv head is an acceptable alternative.

The choice of type of screws will take into account the relative hardness of the materials to avoid galling problems.

Concerning specific screws, particular care will be taken with the shapes of the screws to limit the stress concentrations.

In the case of assembling parts made of polymer or light alloy, the use of dedicated inserts is required so as to limit the risk of damage to the threads during successive assembly and disassembly. If for some reasons such inserts are is not compatible with parts dimensions, a specific tightening torque calculation may be necessary to prevent possible tearing off of the threads during assembly.

The nature of the thread lock will be chosen so as to ensure easy disassembly of the screws after testing. The use of the strong thread lock is not recommended.

- Deliveries :

For each assembly, the following information will be provided: type of screws, quantity, class, tightening torque (if not "ONERA/DS standard") and, if necessary, the type of lubrication and the securing/locking solution. This information will be indicated on the drawings or on the assembly instructions.

Provide spare screws, especially for "aero" or non-standard screws, and in the case of assemblies for which several dis-assemblies are planned during one test campaign.

c) Welded connections

The welded joints must be suitably dimensioned, particularly with respect to the stresses due to dynamic stresses. The calculation of these alternating stresses and the potential damage must be done in accordance with Eurocode 3 standard NF-P-22-311-9, part 1-8.

In the case where a welded connection is selected, a welding booklet should be prepared with welding characteristics, processes, materials and metal filler (DMOS) as well as the qualification (QMOS) required for welding execution, according to the model defined by the French “Institut de Soudage” for example, and according to the AWS codes, AISC, …

d) Frictional force transmission

If the design requires it, a solution based on the transmission of loads by friction may be used, provided that it satisfies the following conditions:

- the coping with loads does not concern one of the primary parts of a structure;
- the safety factor on the coefficient of friction between the parts in contact proposed by the designer has been validated by one of the ONERA / DS design offices;
- a failure of the friction-based solution does not lead to an increase in the aerodynamic loads on a whole model.

e) Other connections

For elements in moving contact (sliding or rotating), the used coefficient of friction, the admitted contact pressure and the corresponding recommended lubrication will be indicated.

The calculation note must also justify the sizing of any motorization integrated into the Test Device, and specify its characteristics: position repeatability, absolute accuracy of positioning, braking.

6.4 DEFORMATIONS

Displacements or deformations that may involve a variation of the hypotheses on the forces (ex: change of the aerodynamic forces) or stress assessment (ex: additional contacts involving a different distribution of stresses) must be checked in the stress report.

In the case of full models, the right and left lifting surfaces must be designed to ensure identical deformation and vibratory behavior.

6.5 STABILITY AND DYNAMIC BEHAVIOUR

6.5.1 Static divergence

A safety factor of 3 is to be considered for the calculation of divergence of the elements constituting the Test Device.

6.5.2 Dynamic divergence and flutter

A safety factor of 2 is to be retained in addition to the dynamic percentage factors indicated above. It should be noted that a design approach based on a comprehensive monitoring device during the test (gauges, accelerometers, etc.) which allows to limit in real time the maximum stresses in the structure likely to suffer from flutter onset is admissible. However, such an approach must be presented at the beginning of the design phase to an ONERA/DS Design Office in order to be validated.

6.5.3 Risk of mechanical coupling

All subassemblies which present a risk of mechanical coupling, the breakage of which could affect the safety of facilities, shall be the subject of a calculation of natural frequencies, at least with indication of the limit conditions used to represent their clamping in the calculation. It will also be verified that the loss of such an element does not constitute a dimensioning load case for the overall behavior of the concerned Test Device. The coupling risks of the modes will be systematically considered for the elements with rotation movements.

7 OTHER REQUIREMENTS

7.1 MARKING

Each mechanical part which composes the Test Device must be permanently marked with the number of the corresponding drawing.

Note: the marking technique (engraving, laser marking, chemical marking, etc.) must take into account the stresses that the part will encounter. The marking must not lead to crack initiation / rupture, for example in the case of a part submitted to pressure.

7.2 REFERENCES

All the possibilities of setting up permanent reference points on the Test Device will be studied to ease the use of the latter:

- equip full models and test rigs with markers allowing alignment with respect to the test section axis (alignment pins for example);
- materialize the fuselage horizontal reference (FHR) on half-models;
- add markers in % of chord, to help position transitions or MDM markers;
- if applicable, provide loading points for the checking and centering of the various balances fitted to the model or the test rig, including on weighed moving surfaces (Note: when it is necessary to calibrate hinge moment balances, it is necessary to provide devices for the application of loads distributed over the span of this surface).

7.3 HANDLING AND OPERATION

7.3.1 Handling

For all parts whose dimensions and / or weight do not allow handling by a single person, the designer will provide handling devices adapted to the concerned test facility (lifting points, extraction points or gripping points). He will ensure the balance of these pieces alone and their size in comparison of the preparation rooms or cells. The drawings of these parts will specify their weight and the position of their COG.

In the case of large Test Devices, their splitting into subassemblies may be required in order to allow their handling and to access the preparation rooms and the test section. The design and manufacturing of specific handling devices (lorries, lifting beams, etc.) may be required. The design of such equipment should be discussed with Test Managers and / or Installation Managers for validation.

All parts will be delivered carefully deburred and cleaned.

All protruding, sharp and / or fragile parts shall be provided with appropriate and reusable protections.

7.3.2 Operation

a) General rules

The design of a Test Device shall be made in such a way as to:

- guarantee fidelity during assembly / disassembly operations;
- limit as much as possible parasitic air circulation in the model or the test rig;
- optimize accessibility to internal instrumentation (assembly order of covers, inspection hatches, etc.);
- ensure the simplicity of configuration changes (minimum number of screws, ...);
- guarantee good accessibility for tools;
- guarantee, when necessary, the installation of balance locking pins;
- take into account the thermal conditions of the test facility.

b) Covers

Particular attention is to be paid to the design and securing of covers. The connection must take into account their behavior under thermal expansions, vibrations and pressure effects. Their mating joints should, if possible, be located downstream of the transition trigger zones.

c) Rotating parts

For Test Devices with rotating parts, the areas of addition or removal of material will be determined, the balancing class will be defined, balancing will be carried out preferably on assemblies which will not be disassembled after balancing (otherwise a very accurate azimuthal marking of the various parts will be performed). A copy of the balancing report will be forwarded to the wind tunnel staff. The lifetime of the rotating elements will be defined in the stress report. Whenever possible, sealed bearings will be preferred. Otherwise, the exact lubrication procedure and its frequency will be given by the designer. The use of a lost oil lubrication device must be subject to prior agreement with the wind tunnel staff.

d) Surface conditions

Finishing of the surfaces of a model or a test rig must be chosen taking into account the constraints in the test: resistance to solvent paints, compatibility of surface conditions with specific test techniques such as infrared measurements, PSP measurements (according to specific recommendations for optical measurements)…

e) Spare parts

For wear parts, a stock of spare parts will be provided if necessary.

8 EQUIPMENT

8.1 GENERAL RULES

The designer shall provide a drawing or equipment diagram of the Test Device, indicating the characteristics of the planned sensors and their locations. **The various connections required for the model equipment (electrical, hydraulic, pneumatic, mechanical, etc) must be designed in agreement with the Wind-Tunnel Managers.**

8.2 SENSORS

8.2.1 Installation

The installation of the pressure taps will be guided by the requirements of measurement during tests but also, as far as possible, by the constraints related to the control of these pressure taps during the preparation phase of the test.

The recommended minimum diameter for the taps is 0.3mm. External surface pressure taps must be protected against clogging by suitable means (specific adhesive tape or other) during the delivery of the Test Device.

8.2.2 Connection

The connection of pressure taps will be made either with flexible vinyl tubes (diameter 0.8 - 1.7 mm) or annealed stainless steel pipe (diameter 0.6 - 1 mm). **The use of silicone tube is prohibited**. When using a large number of taps, the connection is made via PSI connector (see example in **Appendix A**). The connector standard to be used is to be defined in agreement with the Test Manager.

8.2.3 Specific cases

For Test Devices equipped with nacelles, it is necessary to systematically install internal static pressure taps in the various nacelles, even if the latter are symmetrically located on the Test Device. The hypothesis of symmetry no longer applies when sideslip excursions are performed. For thick rear ends, it is mandatory to install a pressure tap in order to allow for corrections to be made. The need for one or more pressure taps to allow for cavity or cutoff pressure correction should be discussed with the test manager when designing the Test Device.

8.3 OTHER SENSORS

If necessary, ONERA / DS will be able to provide the designer with the dimensions of some usual sensors to be installed in the Test Device. The installation of these sensors, proposed by the designer, must be validated by the wind-tunnel staff. Protection devices will be provided for particularly fragile sensors. If technically possible, access hatches (or covers) must allow quick access to the instrumentation.

8.4 ROUTING OF ELECTRICAL CABLES, CONNECTORS AND VINYL TUBES

The designer must take into account the routing of electrical wiring and associated plugs and the routing of the pressure tubes present on the Test Device. There should be no sharp angles in the cable routings which will also have sufficient radii of curvature. As far as possible, the designer will favor full aperture passages to avoid having to dismount wires from connectors.

The decoupling around the balance must be carefully studied: routing, electromagnetic compatibility, cable stiffness......

8.5 REFERENCE SURFACE

It is necessary to plan the provision for a level support on the Test Device to position the calibration clinometers in pitch and roll. This concerns not only the Test Device, but also the moving surfaces where appropriate (motorized or weighed components). The designer will systematically contact wind-tunnel staff to know the specificities of each facility to design this support (size, weight, positioning repeatability ...).

Zero angle and sideslip trim: as far as possible, a surface allowing the permanent installation of a double spirit level (pitch and roll) is to be planned. This spirit level will be covered with a transparent cover the thermal expansion of which will be assessed with respect to adjacent metallic parts.

8.6 MOTORIZED SYSTEMS

The specifications of model motorizations have to be chosen in close agreement with the wind-tunnel staff.

These systems must have, as far as possible, an active safety system (clamping or return to a safety position due to lack of energy). Otherwise, it must be justified that a loss of control of the system does not cause any effort incompatible with the integrity of the Test Device or endanger the personnel during the preparation phases. These systems must be equipped with limit switches and electrical protection (fuse or thermal protection).

More generally, the designer must ensure that all safety regulation requirements to ensure operator safety (Directive Machines, ESP, ATEX…) have been taken into account and fulfilled.

8.7 ELECTRICAL SAFETY

French standards concerning electrical equipment and their conditions of use are entirely applicable to Test Devices in the test facility environment.

For all specific configurations (high voltages, etc.) the designer must initiate a discussion with the wind-tunnel staff in the preliminary design stage, to define the best way to provide the necessary protection to the staff.

9 CONTROLS

9.1 GENERAL RULES

The delivery of a Test Device, the supplying of materials and components, the manufacturing itself, the controls and the associated checks – must be made in conformity with the design file.

Control reports allowing the Test Device acceptance have to be delivered. The reports should address the following topics: materials, thermal treatment, geometry, surface condition, assemblies, screws, equipment, cabling, any other components and the eventual derogations. If necessary, these reports will address the simulation of loads, the performance of hydrostatic tests, the balancing of the rotating parts, or the validation of motorizations.

The control requirements are under the responsibility of the designer and the customer. They are established at the end of the design. The specification of the controls is an output of the design and as such is an integral part of the design file.

These controls following manufacture must be performed for all configurations. Whenever possible, it is necessary to check the assemblies as early as possible in the manufacturing process. It is recommended that these preliminary fitting tests be done in the presence of the Wind Tunnel Manager and / or Test Manager.

The Test Device provider must ensure that all parts conform to the drawings and that any necessary corrective action should be taken care of BEFORE the model is shipped to the wind-tunnel facility.

9.2 MATERIALS CONTROLS

Checks of the integrity of structural materials using non-destructive methods for defect detection (dye penetrant, magnetic particle, ultrasound, radiography...) may be required, especially for structural primary parts. The choice of the most appropriate method depends on the nature and shape of the parts to be inspected.

In the case of composite materials, suitable methods may be used to ensure that the risks of delamination, inclusion, contamination are excluded. The orientation of the fibers should be recorded.

The supply of material certificates for structural materials is required.

9.3 GEOMETRY CONTROLS

Comprehensive checks of tolerances and surface conditions should be performed.

These checks should be, if necessary, taken into account to check that the conclusions of the stress assessment are not modified.

9.4 ASSEMBLIES CONTROLS

9.4.1 Screws

Compliance with the recommended tightening torques will be ensured by the systematic use of calibrated torque tools or devices directly measuring the pre-stressing.

The class of screws and assembly procedures (greasing, locking ...) will be controlled.

9.4.2 Welding

The welded elements are subject to special inspections during the manufacturing which are specified in the welding files in accordance with the standards: welder qualification, process qualification on test specimen, etc. controlled by an official body independent of the manufacturer.

In the case where a welded joint is retained for the primary parts of a structure or for elements whose breakage would lead to the separation of parts of a Test Device (flap tracks for example), during a wind tunnel test, the weld joints will have to be thoroughly checked (by dye penetrant, magnetoscopy, ultrasound, radioscopy or radiography to be determined) to make sure of their realization (absence of cracks, blisters, inclusions ...).

9.5 LOADING SIMULATION

After examining the stress report, ONERA may require checks of the behaviour under load. These checks are mandatory in the following cases:

- use of composite materials: 150% of the nominal static load or 100% of the equivalent static stress (in the case of parts stressed by fatigue) at the extreme temperatures of the expected test domain;
- pressurized system: 143% of the maximum permissible pressure with simulation of other loads if the configuration of the Test Device requires it;
- Control surfaces motorization: 100% of maximum loads.

The procedures used for verifying the behaviour under load must be provided along with the control specification.

9.6 EXEMPTIONS

Nonconformities are the subject of a request for exemption justified, if necessary, by the provision of additional calculations. If necessary, the repair procedures are subject to this procedure.

10 CHEMICAL PRODUCTS

If it is the case, the safety data sheets of chemical products used for the device manufacturing (resin, glue, etc.) or operation (oil, fuel, etc.) have to be sent to ONERA as early as possible, for Safety Service acceptance.

11 TEST DEVICE ACCEPTANCE

A Test Device Acceptance Review with customer and wind tunnel representatives (Test Engineer or Facility Manager) must be planned.

The aim of this acceptance review is to be sure that the status of model before delivery is in-line with design file, from the mechanical point of view and also dealing with the equipment and connections (hydraulic, pneumatic, electrical, …).

This review is also the opportunity to make a global pre-mounting of the different test configurations, including, if possible, wind tunnel interfaces or templates.

12 USER MANUAL

The manufacturer (designer) of the Test Device establishes the user manual including:

- exploded views of the various configurations, with indication of the number of involved parts ;
- assembly instructions;
- configuration change procedures;
- periodic inspections;
- log book to allow for significant incidents and events to be recorded.

13 TEST DEVICE SHIPPING AND DELIVERY

The shipping box must be strong enough and designed to allow its handling using a fork lift or overhead crane with slingson and off a lorry or elevator. The internal design of the box must ensure that all the various parts cannot move inside. In case of very fragile parts, it is necessary to install shock detectors in the box.

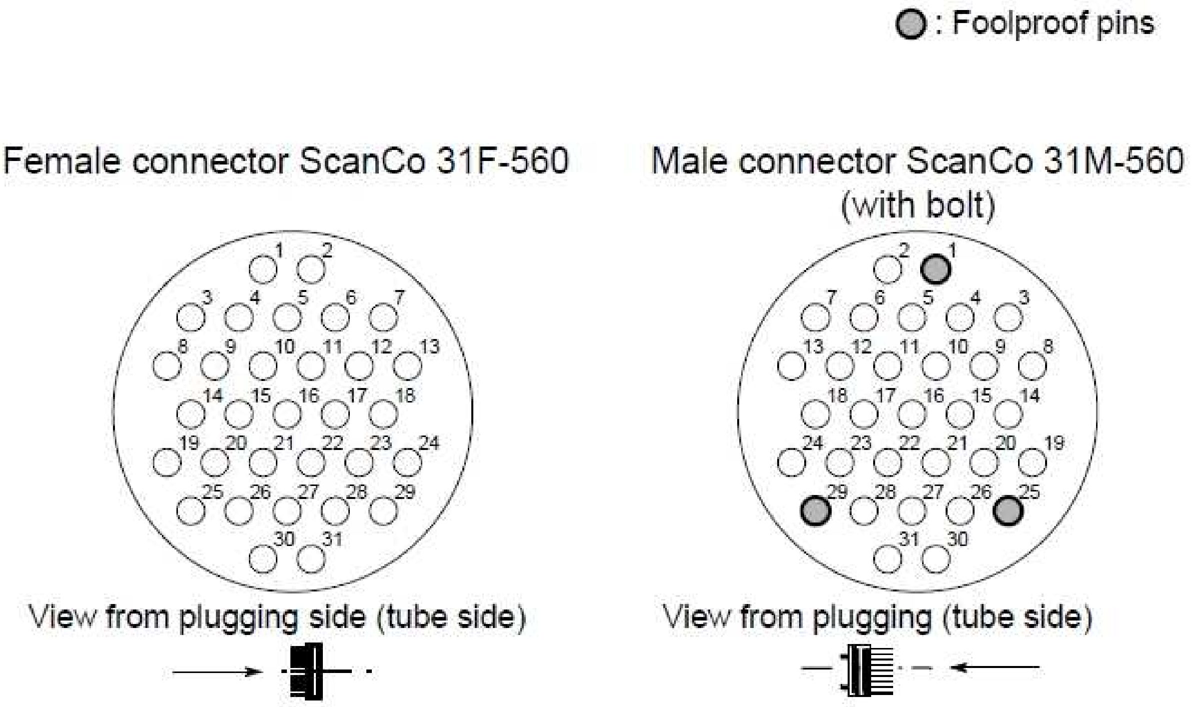
A list of all parts put inside each box must be placed in the box itself, before shipping. Pictures of different layers of parts have to be provided to ease putting parts back into the box after the wind tunnel test. If necessary, specific instructions relative to conservation and storage of the Test Device and associated elements must also be provided.

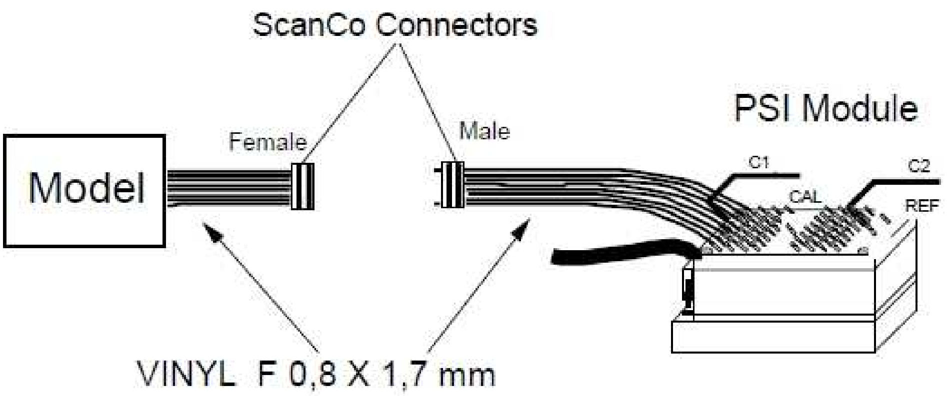
Depending on the required confidentiality level, the customer has to decide which information is necessary to put on the outside panels of each box.

Taking into account the sensitive nature of these materials (cost and confidentiality), ONERA recommends that the Test Device be delivered by means of “door to door “ transportation rather than “collection” (risk of non-direct transportation).

APPENDIX A – CONNECTION OF PRESSURE TAPS (F1 EXEMPLE)

Pressure tap tubing interface





APPENDIX B – STANDARD TABLE OF TIGHTENING TORQUES (1/2)

ONERA THE FRENCH AEROSPACE LAB

Force max et couple de serrage des vis 6 pans creux de classe 8.8, 10.9 et 12.9 pour une contrainte de 50% Re

Mise à Jour 26-oct.-12

Annexe 1 de la Procédure AQ/GMT/PG/0410-1.0

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Les valeurs sont obtenues avec les hypothèses suivantes :

- Utilisation de la procédure Onera AQ/GMT/PG/0410-1.0 - CALCUL DU COUPLE DE SERRAGE DES VIS
- La valeur de force maximale applicable à la vis indiquée dans le tableau assure le non-décollement de l'assemblage et une contrainte dans la vis <80% Re
- Vis M1.6 à M14 : Les vis utilisées sont neuves, soit un assemblage légèrement huilé (f = 0,15 - Normal)
- Vis M16 à M42 : Les vis utilisées sont neuves, soit un assemblage graissé (f = 0,10 - Italique)
- L'outil de serrage utilisé a une précision ≤+/-10%
- On considère que la longueur filetée de l'assemblage respecte Lf ≥1xØvis pour l'acier ou Lf ≥1,5xØvis pour l'aluminium
- Les couples des vis sans tête sont basés sur l'expérience

	Vis au pas normal tête cylindrique CHC (ISO 4762) et/ou tête basse							Vis au pas fin tête cylindrique CHC (ISO 4762) et/ou tête basse						
	Classe de vis / Ø	F = Force max applicable à la vis (N)			C = Couple de serrage (N.m)			F = Force max applicable à la vis (N)			C = Couple de serrage (N.m)			Classe de vis / Ø
		Classe 8.8	Classe 10.9	Classe 12.9	Classe 8.8	Classe 10.9	Classe 12.9	Classe 8.8	Classe 10.9	Classe 12.9	Classe 8.8	Classe 10.9	Classe 12.9	
Légèrement huilé (f = 0,15)	M 1,6	240	338	405	0,10	0,14	0,17	-	-	-	-	-	-	-
	M 2	399	562	674	0,21	0,29	0,35	-	-	-	-	-	-	-
	M 2,5	666	936	1 123	0,40	0,56	0,68	-	-	-	-	-	-	-
	M 3	1 000	1 406	1 687	0,74	1,03	1,24	-	-	-	-	-	-	-
	M 4	1 731	2 434	2 921	1,67	2,35	2,82	-	-	-	-	-	-	-
	M 5	2 834	3 986	4 783	3,34	4,69	5,63	-	-	-	-	-	-	-
	M 6	3 998	5 622	6 747	5,62	7,90	9,48	-	-	-	-	-	-	-
	M 8	7 340	10 322	12 386	13,60	19,12	22,95	8 059	11 333	13 600	14,70	20,68	24,81	M 8 x 1
	M 10	11 689	16 438	19 726	26,75	37,61	45,13	12 593	17 709	21 250	28,46	40,02	48,02	M 10 x 1,25
	M 12	17 046	23 971	28 765	46,00	64,68	77,62	19 254	27 076	32 491	50,86	71,52	85,82	M 12 x 1,25
	M 14	23 410	32 921	39 505	72,77	102,34	122,81	25 986	36 543	43 852	79,30	111,52	133,82	M 14 x 1,5
Graissé (f = 0,10)	*M 16*	*35 536*	*49 972*	*59 966*	*87,87*	*123,56*	*148,28*	*38 703*	*54 426*	*65 311*	*93,09*	*130,91*	*157,09*	*M 16 x 1,5*
	M 18	*43 238*	*60 804*	*72 965*	*121,43*	*170,77*	*204,92*	*50 350*	*70 804*	*84 965*	*134,62*	*189,31*	*227,17*	*M 18 x 1,5*
	M 20	*55 524*	*78 081*	*93 698*	*170,84*	*240,25*	*288,30*	*63 522*	*89 328*	*107 194*	*186,89*	*262,82*	*315,38*	*M 20 x 1,5*
	M 22	*69 338*	*97 507*	*117 008*	*231,96*	*326,20*	*391,43*	*78 221*	*109 998*	*131 998*	*251,14*	*353,16*	*423,79*	*M 22 x 1,5*
	M 24	*79 955*	*112 437*	*134 925*	*294,33*	*413,90*	*496,68*	*89 511*	*125 874*	*151 049*	*317,44*	*446,40*	*535,68*	*M 24 x 2*
	M 27	*105 164*	*147 886*	*177 464*	*428,01*	*601,89*	*722,27*	*116 047*	*163 191*	*195 829*	*456,67*	*642,19*	*770,62*	*M 27 x 2*
	M 30	*127 862*	*179 806*	*215 767*	*585,82*	*823,81*	*988,57*	*146 016*	*205 335*	*246 402*	*639,48*	*899,27*	*1079,12*	*M 30 x 2*
	M 33	*159 276*	*223 982*	*268 778*	*791,67*	*1 113,29*	*1 335,95*	*179 418*	*252 306*	*302 767*	*855,52*	*1203,07*	*1443,69*	*M 33 x 2*
	M 36	*186 958*	*262 909*	*315 491*	*1 019,74*	*1 434,01*	*1 720,81*	*201 399*	*283 217*	*339 860*	*1 071,37*	*1506,61*	*1807,93*	*M 36 x 3*
	M 39	*224 577*	*315 812*	*378 974*	*1 306,01*	*1 836,57*	*2 203,88*	*240 345*	*337 985*	*405 581*	*1 365,31*	*1919,97*	*2303,96*	*M 39 x 3*
	M 42	*257 243*	*361 747*	*434 097*	*1 620,46*	*2 278,77*	*2 734,52*	*282 724*	*397 580*	*477 096*	*1 723,82*	*2424,12*	*2908,94*	*M 42 x 3*

	Vis au pas normal tête HC (ISO 4017)									Vis au pas normal sans tête (ISO 4026)				
	Classe de vis / Ø	F = Force max applicable à la vis (N)				C = Couple de serrage (N.m)				F = Force max applicable à la vis (N)		C = Couple de serrage (N.m)		Classe de vis / Ø
		Classe 8.8	Classe 10.9	Classe 12.9	Classe 14.9	Classe 8.8	Classe 10.9	Classe 12.9	Classe 14.9	Classe 12.9	Classe 14.9	Classe 12.9	Classe 14.9	
Légèrement huilé (f = 0,15)	M 1,6	240	338	405	473	0,10	0,14	0,17	0,20	-	-	-	-	M 1,6
	M 2	399	562	674	786	0,21	0,29	0,35	0,41	-	-	-	-	M 2
	M 2,5	666	936	1 123	1 310	0,41	0,58	0,70	0,82	-	-	-	-	M 2,5
	M 3	1 000	1 406	1 687	1 968	0,74	1,03	1,24	1,45	-	-	0,47	0,55	M 3
	M 4	1 731	2 434	2 921	3 408	1,67	2,35	2,82	3,29	-	-	1,16	1,360	M 4
	M 5	2 834	3 986	4 783	5 580	3,28	4,61	5,53	6,45	-	-	1,95	2,280	M 5
	M 6	3 998	5 622	6 747	7 871	5,62	7,90	9,48	11,06	-	-	3,92	4,570	M 6
	M 8	7 340	10 322	12 386	14 451	13,60	19,12	22,95	26,77	-	-	8,25	9,630	M 8
	M 10	11 689	16 438	19 726	23 014	26,75	37,61	45,13	52,66	-	-	16,54	19,300	M 10
	M 12	17 046	23 971	28 765	33 560	46,00	64,68	77,62	90,56	-	-	29,60	34,600	M 12
	M 14	23 410	32 921	39 505	46 089	72,77	102,34	122,81	143,27	-	-	-	-	M 14
Graissé (f = 0,10)	*M 16*	*35 536*	*49 972*	*59 966*	*69 961*	*87,87*	*123,56*	*148,28*	*172,99*	-	-	70,40	82,100	M 16
	M 18	*43 238*	*60 804*	*72 965*	*85 125*	*121,43*	*170,77*	*204,92*	*239,07*	-	-	135,40	158,000	M 18
	M 20	*55 524*	*78 081*	*93 698*	*109 314*	*170,84*	*240,25*	*288,30*	*336,35*	-	-	-	-	M 20
	M 22	*69 338*	*97 507*	*117 008*	*136 510*	*233,89*	*328,90*	*394,69*	*460,47*	-	-	-	-	M 22
	M 24	*79 955*	*112 437*	*134 925*	*157 412*	*294,33*	*413,90*	*496,68*	*579,46*	-	-	-	-	M 24
	M 27	*105 164*	*147 886*	*177 464*	*207 041*	*430,93*	*606,00*	*727,20*	*848,40*	-	-	-	-	M 27
	M 30	*127 862*	*179 806*	*215 767*	*251 728*	*589,37*	*828,81*	*994,57*	*1 160,33*	-	-	-	-	M 30
	M 33	*159 276*	*223 982*	*268 778*	*313 575*	*791,67*	*1 113,29*	*1 335,95*	*1 558,61*	-	-	-	-	M 33
	M 36	*186 958*	*262 909*	*315 491*	*368 073*	*1 024,93*	*1 441,31*	*1 729,58*	*2 017,84*	-	-	-	-	M 36
	M 39	*224 577*	*315 812*	*378 974*	*442 136*	*1 318,48*	*1 854,11*	*2 224,94*	*2 595,76*	-	-	-	-	M 39
	M 42	*257 243*	*361 747*	*434 097*	*506 446*	*1 634,75*	*2 298,86*	*2 758,64*	*3 218,41*	-	-	-	-	M 42

APPENDIX B – STANDARD TABLE OF TIGHTENING TORQUES (2/2)

ONERA THE FRENCH AEROSPACE LAB

Force max et couple de serrage des vis 6 pans creux de classe 8.8, 10.9 et 12.9 pour une contrainte de 50% Re

Mise à Jour
26-oct.-12

Annexe 1 de la Procédure AQ/GMT/PG/0410-1.0

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Les valeurs sont obtenues avec les hypothèses suivantes :
- Utilisation de la procédure Onera AQ/GMT/PG/0410-1.0 - CALCUL DU COUPLE DE SERRAGE DES VIS
- La valeur de force maximale applicable à la vis indiquée dans le tableau assure le non-décollement de l'assemblage et une contrainte dans la vis <80% Re
- Vis M1.6 à M14 : Les vis utilisées sont neuves, soit un assemblage légèrement huilé (f = 0,15 - Normal)
- Vis M16 à M42 : Les vis utilisées sont neuves, soit un assemblage graissé (f = 0,10 - Italique)
- L'outil de serrage utilisé a une précision ≤+/-10%
- On considère que la longueur filetée de l'assemblage respecte Lf ≥1xØvis pour l'acier ou Lf ≥1,5xØvis pour l'aluminium
- Les couples des vis sans tête sont basés sur l'expérience

Légèrement huilé (f = 0,15)

Classe de vis / Ø	Vis au pas normal tête bombée (ISO 7380) F = Force max applicable à la vis (N)			C = Couple de serrage (N.m)			Vis au pas normal ajustée / épaulée (ISO 7379) F = Force max applicable à la vis (N)			C = Couple de serrage (N.m)			Classe de vis / Ø
	Classe 8.8	Classe 10.9	Classe 12.9	Classe 8.8	Classe 10.9	Classe 12.9	Classe 8.8	Classe 10.9	Classe 12.9	Classe 8.8	Classe 10.9	Classe 12.9	
M 1,6	-	-	-	-	-	-	-	-	-	-	-	-	M 1,6
M 2	399	562	674	0,20	0,28	0,34	-	-	-	-	-	-	M 2
M 2,5	666	936	1 123	0,40	0,56	0,68	-	-	-	-	-	-	M 2,5
M 3	1 000	1 406	1 687	0,74	1,05	1,26	-	-	-	-	-	-	M 3
M 4	1 731	2 434	2 921	1,71	2,41	2,89	-	-	-	-	-	-	M 4
M 5	2 834	3 986	4 783	3,45	4,86	5,83	2 834	3 986	4 783	3,41	4,79	5,75	M 5
M 6	3 998	5 622	6 747	5,70	8,02	9,62	3 998	5 622	6 747	5,95	8,37	10,04	M 6
M 8	7 340	10 322	12 386	13,91	19,55	23,47	7 340	10 322	12 386	14,09	19,81	23,78	M 8
M 10	11 689	16 438	19 726	27,48	38,64	46,37	11 689	16 438	19 726	27,96	39,32	47,19	M 10
M 12	17 046	23 971	28 765	48,13	67,68	81,22	17 046	23 971	28 765	50,26	70,68	84,81	M 12
M 14	-	-	-	-	-	-	-	-	-	-	-	-	M 14
M 16	32 237	45 334	54 401	119,24	167,68	201,22	32 237	45 334	54 401	121,93	171,46	205,75	M 16
M 18	-	-	-	-	-	-	-	-	-	-	-	-	M 18
M 20	-	-	-	-	-	-	-	-	-	-	-	-	M 20
M 22	-	-	-	-	-	-	-	-	-	-	-	-	M 22
M 24	-	-	-	-	-	-	-	-	-	-	-	-	M 24
M 27	-	-	-	-	-	-	-	-	-	-	-	-	M 27
M 30	-	-	-	-	-	-	-	-	-	-	-	-	M 30
M 33	-	-	-	-	-	-	-	-	-	-	-	-	M 33
M 36	-	-	-	-	-	-	-	-	-	-	-	-	M 36
M 39	-	-	-	-	-	-	-	-	-	-	-	-	M 39
M 42	-	-	-	-	-	-	-	-	-	-	-	-	M 42

Légèrement huilé (f = 0,15)

Classe de vis / Ø	Vis au pas normal tête conique FHC à 90° (ISO 10642) F = Force max applicable à la vis (N)			C = Couple de serrage (N.m)		
	Classe 8.8	Classe 10.9	Classe 12.9	Classe 8.8	Classe 10.9	Classe 12.9
M 1,6	240	338	405	0,12	0,17	0,21
M 2	399	562	674	0,25	0,35	0,42
M 2,5	666	936	1 123	0,52	0,73	0,87
M 3	1 000	1 406	1 687	0,86	1,21	1,45
M 4	1 731	2 434	2 921	2,11	2,96	3,55
M 5	2 834	3 986	4 783	4,07	5,73	6,87
M 6	3 998	5 622	6 747	7,00	9,85	11,82
M 8	7 340	10 322	12 386	17,48	24,58	29,49
M 10	11 689	16 438	19 726	33,53	47,16	56,59
M 12	17 046	23 971	28 765	57,92	84,45	97,74
M 14	23 410	32 921	39 505	94,42	132,78	159,33
M 16	32 237	45 334	54 401	144,83	203,67	244,41
M 18	39 161	55 070	66 084	201,93	283,96	340,76
M 20	50 371	70 834	85 001	209,30	408,23	489,88
M 22	-	-	-	-	-	-
M 24	-	-	-	-	-	-
M 27	-	-	-	-	-	-
M 30	-	-	-	-	-	-
M 33	-	-	-	-	-	-
M 36	-	-	-	-	-	-
M 39	-	-	-	-	-	-
M 42	-	-	-	-	-	-

L'utilisation de têtes TORX est fortement recommandée pour cette plage de vis pour éviter d'endommager la tête de vis

APPENDIX C – EQUIPMENT UNDER PRESSURE

Equipment under pressure must be defined at least by:

- its nature: tank, pipe or safety accessory;
- the type of fluid (gas, liquid, vapor in pure phase): group 1 (explosive, flammable, toxic, oxidant) or group 2 (other fluids);
- the maximum allowable pressure (PS): maximum pressure for which the equipment is designed. PS is specified by the manufacturer and indicated on the equipment at a location specified by the manufacturer, i.e. either the location where the protective or safety devices are connected, or the top of the equipment or, if is not appropriate, any other specified location;
- the minimum / maximum permissible temperature (TS): minimum and maximum temperatures for which the equipment is designed, specified by the manufacturer;
- the volume for a tank (V): the internal volume of each compartment, including the volume of the connections up to the first connection or weld joint and excluding the volume of the permanent internal elements;
- the nominal size for a pipe (DN): numerical designation of the dimension common to all elements of a piping system other than the elements indicated by their outside diameter or by the size of the thread; it is a rounded number for reference purposes and does not have a strict relationship with the manufacturing dimensions; the nominal size is indicated by DN followed by a number.

Other information may be indicated:

- the calculation pressure (which is at least the PS);
- the calculation temperature.

The maximum operating pressure is a pressure, lower than PS, which allows the accuracy of safety devices (valve, pressure switch...) to be taken into account. Typically PS - x bar, to be defined with the test and/or the Facility Manager.