Theoretical and Experimental Evaluation of an Indoor Rocket Test Stand

P.A.O.G. Korting* and H.J. Reitsma†
Prins Maurits Laboratory TNO, Rijswijk, The Netherlands

A new indoor test facility for the static firing of solid propellant rocket motors was recently built at the Prins Maurits Laboratory of the Netherlands Organization for Applied Scientific Research. The test stand was designed to withstand an exploding rocket motor and to reduce the noise generated by the combustion gases during static firing. Following an outline of the test stand, some gasdynamical aspects of the indoor test stand are presented. Strength and sound reduction aspects are also treated and the results of verification tests are reported and discussed.

Nomenclature

A = cross-sectional area of tunnel
A_e = exit plane area of nozzle
A_s = surface area of shock wave
c_0 = velocity of sound in air
c_1 = velocity of sound in exploding medium
c_{pa} = heat capacity of air at constant pressure
c_{pg} = heat capacity of combustion gases at constant pressure
D = sound reduction
E_s = shock wave energy
F = sound reduction effect
f = frequency
I_r = normal reflected positive impulse
I_s = side-on positive impulse
L_p = sound pressure level re 20 μ Pa
L_w = sound power level re 10^{-2} W
M = mass per unit area
$\dot{m}_a$ = air mass flow rate
$\dot{m}_g$ = combustion gas mass flow rate
p = pressure
p_a = ambient pressure
p_r = normal reflected shock wave overpressure
p_s = shock wave pressure
p_{so} = shock wave overpressure
$\bar{p}_{so}$ = Sachs scaled shock wave overpressure
p_1 = ambient pressure near nozzle
p_0 = burst pressure
r = distance from explosion point
R = sound insulation in dB
r_1 = distance
S = area covered by sound absorption material
S_0 = exhaust cross-sectional area
$\bar{T}$ = average temperature
T_a = air temperature
T_g = combustion gas temperature
t_p = positive phase period
U_s = shock wave velocity
$\bar{u}$ = average velocity
u_s = flow velocity
V_1 = volume of vessel
v_a = air velocity
v_e = exhaust velocity
W_e = equivalent amount of TNT necessary to generate a certain energy
W_i = equivalent amount of TNT necessary to generate a certain impulse
W_p = equivalent amount of TNT necessary to generate a certain peak overpressure
α = sound absorption coefficient
γ = specific heat ratio of exploding gases
γ_a = specific heat ratio of air
Δp_a = pressure drop
θ = time constant of the shock wave $p(t) = p_s \cdot e^{-t/\theta}$
ρ = density
ρ_a = density of air
ρ_g = density of combustion gases

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*Head, Rocket Technology Section.
†Head, Propulsion Group.

Introduction

UNTIL recently static firing of rocket motors was performed at the Prins Maurits Laboratory TNO in an open test stand consisting of a small building with three concrete walls, a blow-out roof, and an open rear end. This facility was far from ideal, because in case of an accidental explosion of the rocket motor, fragments (metal and burning propellant rests) could be ejected unconstrained. In addition, resulting blast waves could have detrimental effects on personnel and equipment.

Moreover, the noise produced by a static-fired rocket motor was not attenuated during tests in the open test stand. The sound pressure levels resulting from static firing tests are, in general, high, which is obvious from the measured level of 115 dB(A) at a distance of 100 m during a test with a rocket motor producing 45 kN of thrust. Also, because a recreation park was projected in the vicinity of the test area, it was decided to design and build an indoor test stand, with the aim to achieve a substantial sound reduction and to keep blast wave and ejected rocket motor pieces inside.

The concept of an indoor test stand, generated in 1976, is rather unique. As far as we know, only in Japan has an indoor rocket test stand been built.[1] Starting in 1978 the realization of an indoor rocket test stand was seriously pursued and calculations concerning the necessary construction details were initiated. Early in 1980 the construction of the building was started, the indoor rocket test stand was completed at the end of 1980 and put into use in the beginning of 1981.

Outline of the Test Stand

Figures 1 and 2 show the outline of the indoor rocket test stand. The main parts are constructed from reinforced concrete for the purpose of safety and sound insulation.

The actual test stand consists of two intakes, a longitudinal section, and two exhausts. The walls and ceilings are covered with sound absorbing material. Sound reduction is further accomplished by the labyrinth structure of the intakes and exhaust housing. The exhausts are equipped with fans to remove residual gases from the test stand. Before a rocket motor is fired, these fans are moved away electrically from the exhausts to allow the combustion gases to escape into the atmosphere.

Large rocket motors are fired at location A (Fig. 2). The combustion gases flow through the longitudinal section, collide with the backwall, branch off into two directions, and subsequently flow away into the open air after being deflected several times in the labyrinth structure of the exhaust housing. Location B is suited for the firing of small experimental rocket motors. The combustion gases are directed via a pipe into the longitudinal section and removed via the exhausts.

Preconditioning of the rocket motors is possible in a conditioning cabinet in room C; moreover, the test stand is provided with a workshop (D) and a measurement and control room (E).

Gasdynamical Aspects

During static firing of a rocket motor, air mass entrainment occurs due to the jet pumping effect of the exhaust gases. When air mass entrainment is obstructed, the pressure level of the air around the rocket motor will decrease considerably, thus affecting the thrust level of the rocket motor. This can be avoided by a proper design of the test stand and air inlet areas. This requires knowledge of the flow properties in the test stand during a static firing. These properties can be calculated as follows. The hot combustion gases generated in the combustion chamber of the rocket motor leave the motor after expansion in the nozzle and mix with the surrounding air to form a diverging jet stream. This jet stream will collide with the walls somewhere in the tunnel (Fig. 3). If we consider a control surface 1-2-3-4 and assume 1) ideal expansion, 2) stationary and frictionless flow, 3) no chemical reactions in the mixing area, 4) density and pressure at 3-4 equal to ambient density and pressure, and 5) nozzle exit area negligible compared to the cross-sectional area of the tunnel, the laws of conservation are:

1) Conservation of mass:

$$\rho_a v_a A + \rho_g v_e A_e = \rho_a \bar{u} A \tag{1}$$

2) Conservation of momentum:

$$m_a v_a + m_g v_e + p_l A = (m_a + m_g)\bar{u} + p_a A \tag{2}$$

3) Conservation of energy:

$$m_a(c_{p_a} T_a + \tfrac{1}{2} v_a^2) + m_g(c_{p_g} T_g + \tfrac{1}{2} v_e^2) = (m_a + m_g)(c_{p_a} \bar{T} + \tfrac{1}{2}\bar{u}^2) \tag{3}$$

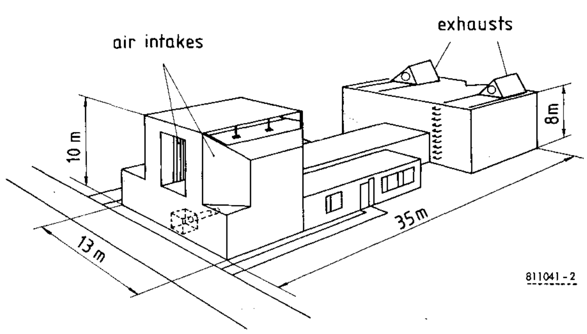

Fig. 1 Indoor rocket test stand.

In addition, Bernoulli's equation holds:

$$p_a = p_l + \tfrac{1}{2}\rho_a v_a^2 \tag{4}$$

Expressions (1-4) are a set of four equations with four unknown parameters: m_a (or v_a), p_l, $\bar{u}$, and $\bar{T}$. One simply derives

$$\bar{u} = -\alpha v_e \pm \sqrt{2\alpha^2 + 2\alpha v_e} \tag{5}$$

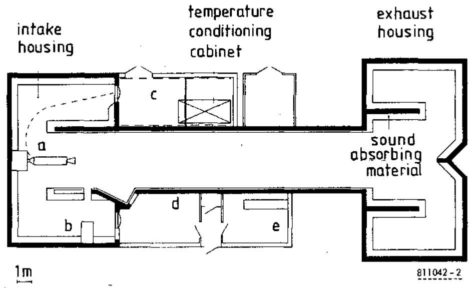

Fig. 2 Floor plan of the indoor rocket test stand.

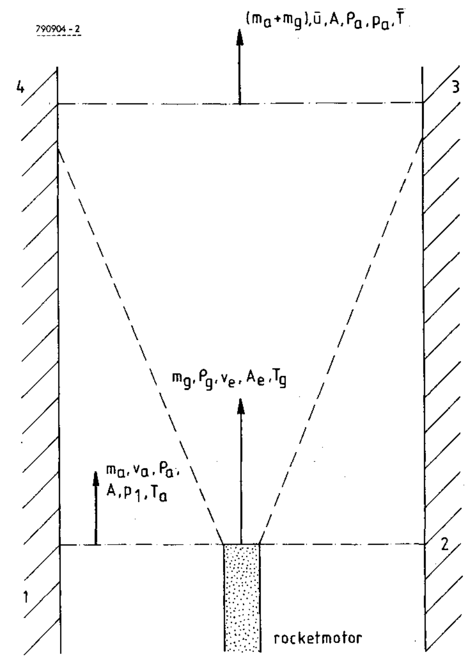

Fig. 3 Diagram of a static-fired rocket with diverging exhaust gases in the test stand tunnel.

Table 1 Flow properties in a test stand during static firing of a typical rocket motor[a]

A, m^2	v_a ms^{-1}	p_l, kPa	m_a, kgs^{-1}	$\bar{u}$, ms^{-1}	$\bar{T}$, K	Δp, kPa
8	119	92.8	1140	122	487	8.5
12	98	95.6	1410	100	452	5.7
16	85	97.0	1640	87	431	4.3
50	49	99.9	2940	49	374	0.4

[a] The following conditions are assumed:

Density atmospheric air, ρ_a	1.20	$kg\,m^{-3}$
Density combustion gases, ρ_g	0.25	$kg\,m^{-3}$
Exit plane nozzle, A_e	$4.8 \cdot 10^{-2}$	m^2
Exhaust velocity, v_e	2552	$m\,s^{-1}$
Heat capacity air, c_{p_a}	1004.5	$J\,kg^{-1}K^{-1}$
Heat capacity combustion gases, c_{p_g}	2151.8	$J\,kg^{-1}K^{-1}$
Temperature air, T_a	300	K
Temperature exhaust gases, T_g	2116	K
Mass flow rate exhaust gases, m_g	30	$kg\,s^{-1}$

$$v_a = \bar{u} - \alpha v_e \tag{6}$$

$$\bar{T} = \frac{m_a h_a + m_g h_g}{c_{p_a}(m_a + m_g)} - \frac{\bar{u}^2}{2c_{p_a}} \tag{7}$$

where

$$\alpha = \frac{\rho_g}{\rho_a} \cdot \frac{A_e}{A} \tag{8}$$

$$h_a = c_{p_a} T_a + \tfrac{1}{2} v_a^2 \tag{9}$$

$$h_g = c_{p_g} T_g + \tfrac{1}{2} v_e^2 \tag{10}$$

It can easily be shown that $\sqrt{2\alpha^2 + 2\alpha} > \alpha$, which means that only the plus sign in Eq. (5) has a physical meaning. In Table 1 these flow properties are calculated for a typical rocket motor for various cross-sectional areas of the tunnel. From this table it can be seen that the velocity of the air mass flow is considerable, especially at relatively small cross-sectional areas of the tunnel. The same applies to the pressure drop at the nozzle exit plane $\Delta p = p_a - p_l$.

It can be concluded that a large cross-sectional area of the tunnel is favorable; to avoid high air velocities in the inlet housing, the air inlet areas have to be of the same order of magnitude. When using splitter-silencers to attenuate the noise produced by a static-fired rocket motor, these inlet areas even have to be enlarged, as, in general, splitter-silencers cannot withstand air velocities of more than 40 ms^{-1}.

Although the dimensions of the tunnel and the inlet area were based on these gasdynamical aspects and although Japanese data support the validity of the calculations,[2] these calculations still need experimental verification. Flow velocity measurements are planned in the near future.

Strength Aspects

TNT Equivalency of Exploding Solid Propellant Rockets

Before calculations concerning the required strength of the construction could be started, it was necessary to have an insight into TNT equivalencies of exploding solid propellant rockets. A difference must be made between propellants containing high-energy binders (such as nitroglycerine) and propellants containing rubberlike binders, because it is generally assumed that a double-base-type propellant detonates more readily than a composite propellant. In the literature TNT equivalencies of up to 40% are mentioned for experiments in which a detonation is initiated by a booster charge. Under normal conditions a rocket propellant rarely detonates, although during malfunction of the rocket motor deflagration of the propellant can occur, mostly followed by a physical explosion of the motor case. However, the yield in TNT equivalency is much lower than 40%[3,4] in such cases.

At the same time the critical diameter of the propellant appears to be an important parameter. Salzman et al.[5] describe a theoretical model from which it is obvious that the porosity of the propellant is of first importance. For instance, for an AP/PU-propellant (composition 75/25) with porosities of 0, 0.5, and 1.0%, respectively, values for the critical diameter obtained amount to 3.68, 2.59, and 0.91 m, respectively. Salzman et al.[5] state that in general an intrinsic porosity of approximately 0.2% is found for composite propellants, which means that the critical diameter for these propellants has an order of magnitude of 1 m or more.

As far as can be seen at the present, the largest rocket motor to be tested in the future at the Prins Maurits Laboratory TNO will contain 300 kg of composite propellant, with a diameter of approximately 35 cm. From the above, a detonation cannot occur in such a rocket motor, and only deflagrations and physical explosions will have to be reckoned with. Critical diameters of double-base rocket propellants are less well known. More precautions are necessary with these types of propellants, although no accidental detonation has been described in the literature up to now.

Blast Effect of a Physically Exploding Rocket Motor

In the following the explosion of a rocket motor is regarded as a physical explosion, which is comparable with the bursting of a pressure vessel ("bursting sphere"). Important for the formation of the shock wave are the burst pressure, the volume, and the aggregation of the medium (in our case supposed to be an ideal gas with $\gamma = 1.21$).

The shock wave energy can be estimated from the internal energy change associated with isentropic expansion of the compressed gases to ambient pressure[6]:

$$E_s = \frac{p_o V_l}{\gamma - 1} \left[1 - \left(\frac{p_a}{p_o} \right)^{(\gamma - 1)/\gamma} \right] \tag{11}$$

The initial strength of the shock wave (the shock wave pressure) is calculated with the aid of the basic shock tube equation[6]:

$$\frac{p_s}{p_a} = \frac{p_o}{p_a} \left[1 - \frac{\frac{c_o}{c_l}(\gamma - 1)\left(\frac{p_s}{p_a} - 1 \right)}{\sqrt{2\gamma_a \left(\gamma_a - 1 + (\gamma_a + 1)\frac{p_s}{p_a} \right)}} \right]^{2\gamma/(\gamma - 1)} \tag{12}$$

which is to be solved iteratively.

The velocity of sound in an ideal gas is given by:

$$c^2 = \gamma p / \rho \tag{13}$$

When it is supposed that the exploding volume is spherical so that $V_l = 4/3 \cdot \pi r_l^3$, the subsequent expansion of the shock wave can be calculated by means of the Brinkley-Kirkwood method[6] for spherical expansion. Only two parameters (p_s and E_s) play a dominant role herein.

Table 2 shows the results of a calculation made for a physical explosion of a rocket motor with a diameter of 35 cm. A local rupture in the motor case resulting in a spherical explosion was assumed. The same kind of calculations were also performed for the explosion of 1 kg of TNT; the results are also presented in Table 2.

The program BKWAVE[6] was used to calculate both shock wave expansions. Results are tabulated in Table 3.

These calculated values were compared with those of the explosion of 1 kg of TNT (not shown). From the ratio of the initial shock wave energies the equivalent TNT weight ratio

Table 2 Shockwave parameters for the explosion of a rocket motor[a] and of 1 kg TNT[b]

Exploding medium	p_{so}, MPa	u_s, ms^{-1}	U_s, ms^{-1}	E_s, MJ
Rocket motor	5.072	1817.7	2232.1	2.013
TNT (1 kg)	58.59	–	–	3.060

[a] Burst pressure $p_o = 30$ MPa, density of the gaseous medium $\rho_l = 29$ kg m^{-3}, specific heat ratio $\gamma = 1.21$.
[b] Density TNT $\rho_l = 1600$ kg m^{-3}.

Table 3 Shock wave expansion of a physical explosion, locally occurring in the rocket motor

r, m	p_{so}, kPa	I_s, Pa.s	E_s/A_s, Jm^{-2}	θ, $10^{-3}\cdot$s	A_s, m^2
0.175	5072	131.15	5.230×10^6	0.0259	0.3849
0.506	1530	147.05	5.692×10^5	0.0971	3.2221
1.014	513.7	104.65	1.099×10^5	0.2151	12.928
2.032	132.3	69.94	1.717×10^4	0.6291	51.872
4.992	28.9	37.58	1.647×10^3	1.8419	313.19
6.923	17.9	28.10	7.383×10^2	2.3352	602.23
10.000	10.8	19.78	3.075×10^2	2.8675	1256.6

can be established so that:

$$W_e = \frac{2.013}{3.06} = 0.658 \text{ kg of TNT}$$

It has also been investigated for various distances what amount of TNT would have been required to cause at the same distance the same peak overpressure W_p, impulse W_i, and energy W_e, respectively. The results are summarized in Table 4.

It is remarkable that, in general, the calculated equivalent amount of TNT increases with increasing distance and that somewhere close to the source the value 1.0 is exceeded.

This phenomenon can be explained[6] by the larger initial shock wave and the shorter positive phase period of a TNT explosion compared with a physical explosion. More energy will be dissipated during a TNT explosion by the higher pressures. This means that at larger distances the pressures resulting from a physical explosion are larger than the pressures from comparably sized TNT explosions.

Calculations were also performed for a physical explosion of a complete rocket motor (volume = 0.2 m^3, burst pressure of sphere = 30 MPa). An initial shock wave energy of E_s = 17.93 MJ was found, which yields an equivalent amount of

$$W_e = \frac{17.93}{3.06} = 5.86 \text{ kg of TNT}$$

At further distances, larger equivalent amounts of TNT are obtained, which is also the result when calculations are based on impulse and pressure. It has to be mentioned that the occurrence of a physical explosion of the whole rocket motor seems unlikely. When a local rupture of the motor-case occurs the combustion process will probably be stopped by depressurization. Moreover the remainder of the propellant will be hurled away as a result of the explosion. Therefore, it is more realistic to work with the data obtained from calculations for a local, limited explosion. After all, it was decided to base further strength calculations on an explosion-equivalency of maximal 6 kg of TNT.

Table 4 Equivalent amounts of TNT for the physical explosion of a sphere with a 0.35 m diameter

Distance, m	W_p, kg	W_i, kg	W_e, kg
0.175	0.06	0.266	0.707
1.0	0.56	1.934	0.917
2.0	1.05	1.847	1.147
5.0	1.28	1.781	1.269
10.0	1.37	1.889	1.335

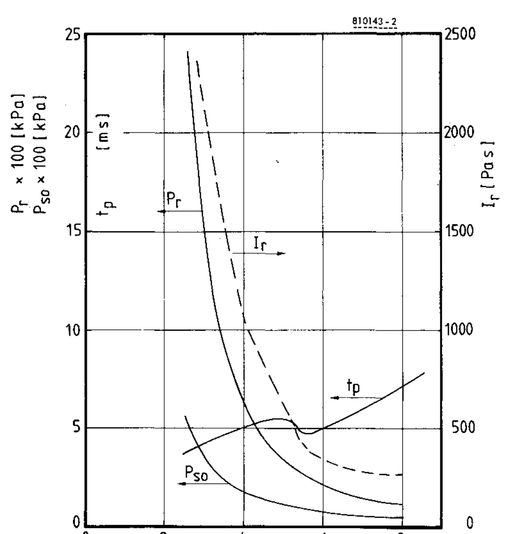

Fig. 4 Shock wave overpressure, normal reflected shock wave overpressure, positive phase period, and normal reflected positive impulse as functions of the distance from the explosion point of 9.9 kg of TNT.

Strength Calculations of Ceiling and Walls of Test Stand

During an explosion in a confined surrounding, reflection of shock waves increases the load exerted on the structure. Therefore the strength calculations of ceiling and walls of the test stand had to be based on an explosion of $6 \times 1.65 = 9.9$ kg of TNT.

Baker[7] has pointed out methods by which relationships between the distance from the explosion point, the shock wave overpressure, and the positive phase period can be derived.

The normal reflected shock wave overpressure and the normal reflected positive impulse are obtained via the following formulas:

$$p_r = 2p_{so} \frac{4p_{so} + 7}{p_{so} + 7} \tag{14}$$

$$I_r = \tfrac{1}{3} p_r t_p \tag{15}$$

Figure 4 shows p_{so}, p_r, t_p, and I_r as a function of the distance from the explosion point of 9.9 kg of TNT.

Further it is assumed that the required strength of the walls and ceilings of the intakes and exhaust housing are governed by the magnitude of p_r and I_r. On the other hand, because attenuation within the longitudinal section is expected to be minimal, the required stength of the walls and ceiling of this section are governed by the magnitude of p_{so} and I_r, as applied at the entrance of the longitudinal section.

Based on these assumptions and allowing elastic deformations only, strength calculations showed that reinforced concrete walls and ceilings having an overall minimal thickness of 0.3 m would be sufficient.

Experimental Verification

To determine the response of the test stand upon blast, 250 g of TNT was brought to detonation in the test stand. Three parameters were measured: acceleration, displacement, and pressure. The locations of the various transducers are indicated in Fig. 5.

Besides experimental data, theoretical data also were obtained by calculations using Sachs scaled air blast parameters.[7] Details of these calculations are presented in Ref. 2.

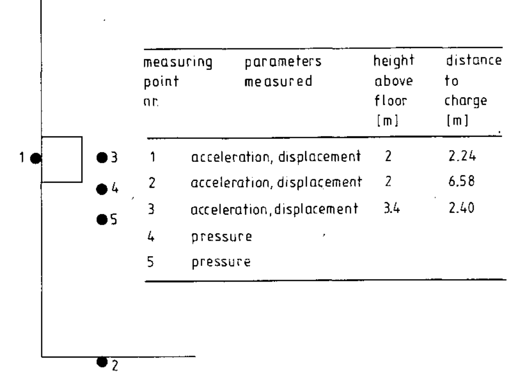

Fig. 5 Location of measuring points in the indoor rocket test stand. TNT charge (250 g) is placed at point 3 (1 m above floor).

The results of the experiment and calculations are summarized in Table 5. Comparison of the calculated normal reflected positive impulse, I_r, and the measured impulse, ρV, shows that the agreement is reasonable for points 2 and 3, whereas for point 1, a considerable discrepancy between calculated and measured impulses exists. A possible explanation may be found in an indirect excitation of the wall by a heavy concrete thrust block, which could affect the response of the wall.

The measured pressures in points 4 and 5 agree well with the calculated data (see Table 5).

During the experiment no displacements were detected by the strain gage transducers. Obviously, the displacements that were excited fell below the noise level of the transducers.

This, together with the fact of reasonable agreement between calculated and measured impulses, gives an indication that the blast of a detonation of 6 kg of TNT will only cause elastic deformations in the test stand structure.

Sound Reduction Aspects

Sound Levels During Rocket Firings

In the past measurements were performed of the sound pressure level generated during the static firing of some relatively large rocket motors. It appeared that rocket motors with a maximum thrust of 45 kN produced sound pressure levels of approximately 115 dB(A) at a distance of 100 m between rocket motor and measuring point. The sound power level can be computed with the formula[8]:

$$L_w = L_p + 10 \log \pi r^2 + F \tag{16}$$

and amounts for the 45 kN thrust producing motor to 161 dB(A) re 10^{-12} W. (F stands for the sound reduction effect due to bushes, trees, energy absorption by the air, etc., and amounts to approximately 1.5 dB(A) per 100 m.)

Another type of rocket motor, producing 35 kN of thrust, generated a sound pressure level of 103 dB(A) at a distance of 200 m, with a corresponding calculated sound power level of 157 dB(A) re 10^{-12} W.

Sound Reduction Value Pursued

A sound pressure level of 70 dB(A) at a distance of 200 m during static firing is considered to be the maximum acceptable level, when produced in the daytime for rather short periods.

The maximum sound power level to occur during future tests is assumed to be 160 dB(A) re 10^{-12} W which, at a distance of 200 m, results in a sound pressure level of 106 dB(A) using Eq. (16).

Hence the required sound reduction amounts to 36 dB(A), which was the design criterion for the test stand with respect to noise suppression. Advice on this subject was obtained through the Technisch Physische Dienst TNO.

Realization of Sound Reduction

A rocket motor is considered, which is static fired in a totally closed test stand. The sound produced will be transferred to the outside depending on the sound insulation capacities of the walls, ceiling, and floor. In general, sound insulation is determined by the mass and stiffness of the material and the construction of walls, ceiling, and floor[8]:

$$R = 17.5 \log \frac{f.M}{500} + 3 \tag{17}$$

As the reinforced concrete walls, ceiling, and floor have a thickness of 0.3 m (ρ concrete $= 2500$ kg m^{-3}), it can be calculated that the minimum sound insulation obtained for the firing noise of the rocket amounts to 50 dB(A) (for a frequency of 250 Hz). This value is considered to be sufficient.

However, the test stand is provided with large intake and exhaust areas, which will act as a severe noise source for the surroundings. Hence the sound level produced by the rocket motor has to be reduced within the test stand. This was achieved by using sound absorbing materials and by deflecting the combustion gases several times.

Sound Reduction Within the Test Stand

Walls and ceiling of the longitudinal section are covered with a 50-mm-thick layer of sound absorbing rock wool, whereas a layer of 200 mm has been used to cover the walls and ceiling of the intakes and exhaust housing. The rock wool layers are covered by a thin high-temperature resistant polyamid foil and a perforated aluminum plate. The sound reduction due to these provisions is given by[8]:

$$D = 10 \log\left(\frac{S}{S_o} \cdot \frac{\alpha}{1-\alpha}\right) \tag{18}$$

The sound reductions achieved in the longitudinal section, the exhaust housing, and the intake housing are calculated separately:

1) *Longitudinal section.* With $S = 340$ m^2, $S_o = 15$ m^2, and $\alpha_{\text{rock wool}} = 0.5$, Eq. (18) yields $D_{\text{longitudinal section}} = 13$ dB.

2) *Exhaust housing.* The combustion gases are deflected four times in the labyrinthine exhaust housing before leaving the test stand. Each bend causes a sound reduction of approximately 10 dB[8], hence $D_{\text{exhaust housing}} = 40$ dB.

3) *Intake housing.* The sound reduction achieved in the labyrinthine intake housing amounts to 20 dB, because the air is deflected twice before entering the longitudinal section: $D_{\text{intake housing}} = 20$ dB.

The theoretical sound radiation at the exhaust housing and intake housing is given by:

$$L_{w_{\text{exhaust}}} = L_{w_{\text{rocket motor}}} - D_{\text{longitudinal section}} - D_{\text{exhaust housing}} \tag{19}$$

and

$$L_{w_{\text{intake}}} = L_{w_{\text{rocket motor}}} - D_{\text{longitudinal section}} - D_{\text{intake housing}} \tag{20}$$

In the case of a rocket motor with a sound power level of 160 dB, the theoretical sound radiation at the exhaust and intake amounts to 107 dB and 127 dB, respectively.

Experimental Verification

For an experimental verification of the sound reduction achieved, two 35-kN thrust producing rocket motors were

Table 5 Experimental and theoretical results for an explosion of 250 g of TNT in the indoor rocket test stand

Measuring point *No.*	Acceleration, ms^{-2}	Velocity, (V), ms^{-1}	I_r, $Pa \cdot s$	ρV, Pa·s	$\eta = \rho V / I_r$,	$\bar{p}_{so}$, calculated,	$\bar{p}_{so}$, measured
1	68	0.040	45.79	100	2.18	–	–
2	11	0.004	14.13	10	0.71	–	–
3	32	0.012	41.94	30	0.72	–	–
4	–	–	–	–	–	2.66	3.09
5	–	–	–	–	–	0.61	0.52

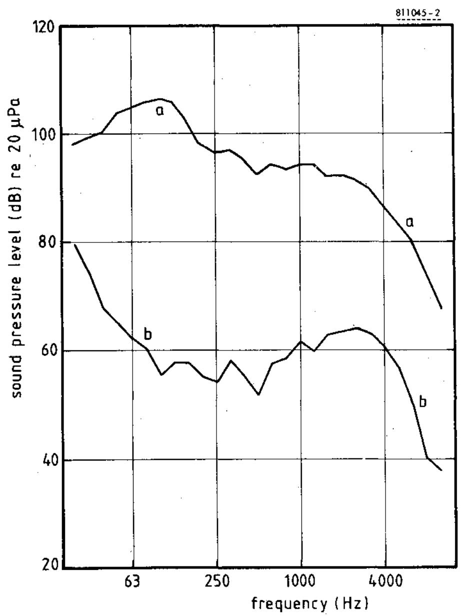

Fig. 6 Sound spectra measured at a distance of 200 m during firing of a 35-kN thrust producing rocket motor in the open test stand (a) and in the indoor test stand (b), respectively.

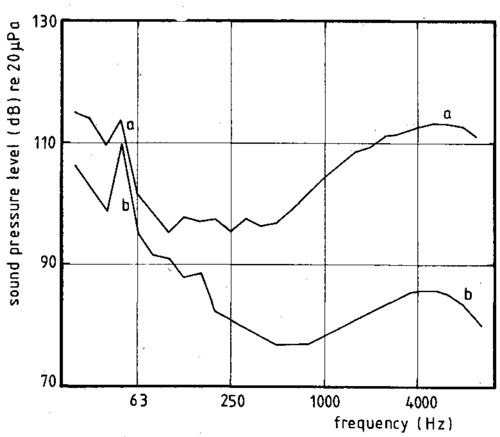

Fig. 7 Sound spectra measured at a distance of 2 m from the inlet tower (a) and outlet tower (b) of the indoor test stand during static firing of a 35-kN thrust producing rocket motor.

fired, one in the open test stand and one in the indoor test stand. From the sound spectra measured at a distance of 200 m (Fig. 6), it is obvious that the sound pressure level is reduced by approximately 30-40 dB as a result of indoor testing, which is in accordance with the expectations.

An additional experiment was carried out to discriminate between the sound produced by the inlet and outlet tower. The results are shown in Fig. 7. The inlet tower appears to produce a 10-30 dB higher sound level than the outlet tower, which is again in accordance with the expectations. Noise reduction in the inlet tower may be further improved by using splitter-silencers that can easily be built in. However, it was decided not to use this option because the sound reduction achieved was considered sufficient.

Conclusions

Various aspects of the newly built indoor rocket test stand were described. It can safely be assumed that the test stand is capable of withstanding an explosion of up to 6 kg of TNT. Based on a literature search and a computation concerning the TNT equivalence of exploding rocket motors, this means that rocket motors containing (composite) propellant masses of up to 300 kg can safely be tested. The test stand reduces the sound level of a static-fired motor by approximately 30 dB(A) at a distance of 200 m, which is in agreement with the calculations. The use of splitter-silencers may further increase this value.

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