A good choice: Why the National Aerospace Laboratory NLR in The Netherlands purchased 18 Task balances in the late 50-ies

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In the late 50-ies a transonic and a supersonic wind tunnel was designed and built in The Netherlands. A crucial question was how forces and moments on the wind tunnel model had to be measured. Today no one questions the use of internal strain gauge balances. But there was a time that this was far from obvious. The paper shows the alternative that was considered at that time. And how, at a very late stage, a decision was made for internal balances. Since there was hardly sufficient time left for the 'in house' development of all required balances, the decision was finally made to buy 18 TASK balances. Some of these balances are still in use today, demonstrating that a good choice was made at that time and that the quality of the original design of the TASK balances was excellent. This paper is a contribution to the special session entitled: "65 Years of TASK Wind Tunnel Balances - Past, Present, and Future".

I. Wind tunnels and balances at NLR 1919 - 1949

At the end of the First World War the decision was made by the Dutch Government to establish an institution specifically dedicated to aeronautical research, the 'Government Service for Aeronautical Studies' ('Rijksstudiedienst voor de Luchtvaart', RSL). The Netherlands obeyed strict neutrality during WWI and in order to preserve neutrality in the future as well, it was deemed essential that The Netherlands had to be independent in aircraft development. It was a wise decision at that time not to restrict the activities of this new institution to military applications only, but to extend the scope to civil use as well. The activities would encompass strength and materials, flight mechanics, aerodynamics and engines [1].

From the beginning a wind tunnel was considered to be an essential part of the laboratory. Its design was largely based on the second wind tunnel built by Eiffel as realized in Auteuil near Paris in 1912 [2]. The diameter of the test section was 1.6 m and the maximum speed around 30 m/sec. The tunnel was ready at the official opening of the laboratory, April 1919. Figure 1 shows someone peeping into the test section while a colleague is busy with the balance on top. Not only the tunnel but also the balance design was inspired by Eiffel (Fig.3). The model was

Figure 1 The 'Eiffel Tunnel', the first wind tunnel of RSL (1919).

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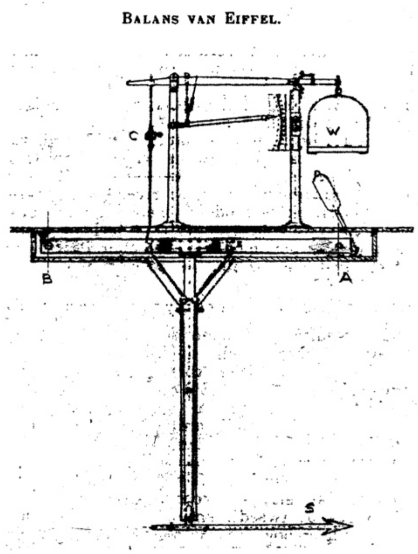

Figure 3 The first Eiffel balance used in the 'Eiffel Tunnel' at the RSL/ NLL. Four runs were required for one data point (see text).

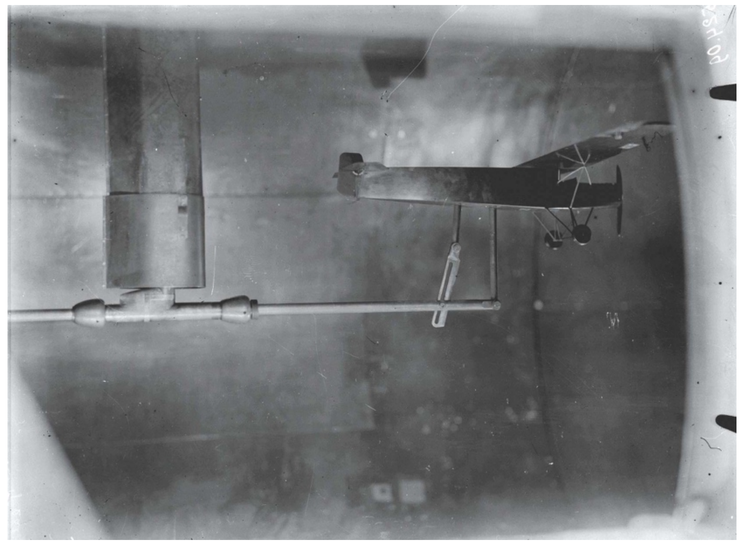

Figure 2 Fokker F.II wind tunnel model mounted in the Eiffel tunnel (early 20-ies).

attached to the sting S, either upright or inverted. The upper part of the support could be rotated around point A or around point B. A conventional 'balance' with the weight W was finally used to measure the aerodynamic load. With this procedure four measurements were required for one condition, more than enough to derive the lift, drag and pitching moment. Fig.2 shows a model attached to the Eiffel balance, in this case a Fokker F.II, an early Fokker design for a passenger aircraft. This test procedure took a lot of time and it was soon decided to support the model by wires that were connected to the balance platform on top of the tunnel (Fig.4). In this way the six forces and moments could be measured simultaneously with six conventional balances.

A. New buildings and new wind tunnels

In 1937 it was decided to split the activities of the 'Government Service for Aeronautical Studies' RSL into a regulatory part and a research part. The latter was named NLL, the 'National Aeronautical Laboratory'♠. This split was a good reason to relocate the laboratory closer to Schiphol Airport and to provide more adequate housing including the construction of two new wind tunnels. These buildings were almost ready at the time that the Second World War reached The Netherlands. The two new wind tunnels were of the Göttinger Type with test section dimensions of 2.1x3 m^2 respectively 1.6x1.6 m^2. Maximum speed was around 70 m/sec. Commissioning of both tunnels took place end of 1940. The smaller of the two tunnels used the external balance of the old Eiffel tunnel. For the larger tunnel, named the Large LST, a new external balance was designed and constructed. Again, the models were supported by wires, attached to a big frame (Fig.6). On top of this frame the balance platform was located that supported six semi-automatic balances. The balances were

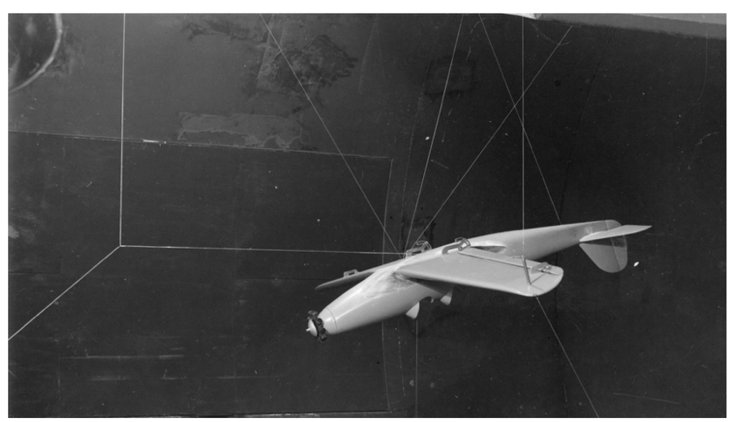

Figure 4 Model suspended on wires in the Eiffel wind tunnel of NLL in the 30-ies.

♠ The RSL (Rijksstudienst voor de Luchtvaart) was founded in 1919 and became NLL (Nationaal Luchtvaart Laboratorium) in 1937. In 1961 the name was changed again into NLR, 'Nationaal Lucht- en Ruimtevaartlaboratorium' to include aerospace in its activities. It is now called the Royal Netherlands Aerospace Centre NLR.

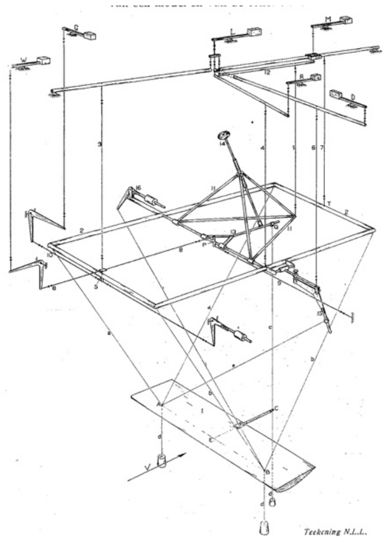

Figure 6 Wire suspension with a frame as used in the Large Low Speed Tunnel LST in 1940.

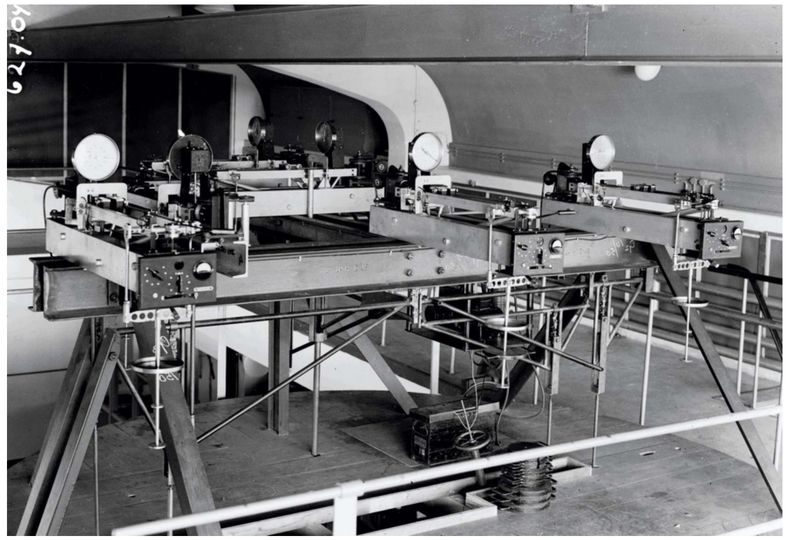

Figure 5 The semi-automatic balances as used in the large LST in combination with the frame and wire suspension system as shown in Fig. 6.

connected with rods to the frame such that the three forces and three moments could be separated properly. Each of the balances had a small electromotor that moved a servo-controlled weight to the equilibrium position. The precise location of this movable weight was subsequently indicated by a dial that had to be read and recorded by hand by an observer (Fig.5). Extra weights were used to compensate for the model weight and the dead-weight to stretch the wires. The system was fast and accurate.

B. A plan for new wind tunnels after the war

Right after the war the Dutch Government focused on the revitalization of the Dutch industry, including the Dutch aeronautical industry with Fokker as the leading company. As an essential part of this effort an assignment was given to NLL to give scientific and technological support, including the building of new wind tunnels [1,3]. These plans comprised the building of a large Low Turbulence Tunnel (LTT; 2.1 x 3 m^2), a High Speed Tunnel (HST; 2.1x 3 m^2) that could be pressurized till 4 bar, a scaled version of the HST (named Pilot Tunnel or PT; scale 1:5) and a small Supersonic Tunnel (SST; 0.4x0.4 m^2). This represented a formidable challenge for NLL, though the staff that designed the low speed tunnels just before the war was still present. However, transonic and supersonic flow meant entering uncharted territory. Basically, NLL essentially had been cut off during the war from high speed aerodynamic developments. Testing close to Mach=1 and beyond was believed to be impossible due to chocking of the test section. Hence the name High Speed Tunnel HST instead of Transonic. A supersonic wind tunnel was even beyond imagination. Fortunately, a German scientist, S.F. Erdmann, who was responsible for the supersonic wind tunnel tests for the V2 in Peenemünde during the war, could be employed through contacts with the Dutch Scientific Intelligence Agency [4]. The plans evolved rapidly. The status at the end of 1949 was as follows. A powerplant for all facilities, based on the steam / turbo-electric installations of three 'Escort Ships' (used in the war but bought very cheap) was 60 % ready. The Low Turbulence Tunnel LTT was in construction with the lower leg in place. The pilot facility PT was about half finished. Ground work had started for the HST. Erdmann had already finished a small, vacuum driven supersonic tunnel with a test section of 3x3 cm^2 (hence called the 'Three-by-Three') to show the essentials of a supersonic tunnel design. There was though one big problem: a large cost overrun. In 1946 the original budget was estimated, extremely optimistically, to be 1.6 million Dutch guilders. This had increased to 12.4 million in February 1949. The Government was not amused. In the same period the financial situation in The Netherlands was seriously under pressure due to the 'loss' of the Dutch East-Indies in 1949. The Government decided to stop all new building activities. Because of this new situation, NLL had to lay off people. Erdmann decided to move to the Technical University Stockholm in Sweden, still involved in supersonics.

II. 1952: A fresh start for the high speed tunnels

It lasted till the beginning of 1952 that the wind tunnel plans were picked up again, but only after some major changes. Van der Maas, a former head of the Flight Division at NLL and since 1940 professor at Delft University, became the chairman of the board of the Foundation NLL. He was a very energetic man and started with some important decisions. Firstly, it was decided to cancel the Low Turbulence Tunnel LTT. A young and very smart engineer, J. Boel, who came from Delft, was made responsible for the realization of the High Speed Tunnel HST. Erdmann was contacted in Sweden and could be persuaded to return to NLL what happened in 1954. The time-out had a positive effect as well. In the years between 1952 and 1955 a number of major decisions were made.

On January 24, 1952, AGARD, the 'Advisory Group for Aeronautical Research and Development' was founded. It facilitated the exchange of knowhow within the transatlantic world of aeronautics. Contacts through AGARD definitely had a large impact on the wind tunnel plans of NLL. Von Kármán, the 'grand old man' of AGARD, advocated to install a true transonic test section in het HST and suggested ways to make some of the required information available, at that time considered 'top-secret' [5]. As a result, a slotted test section was finally selected. However, given the already installed power, the test section dimensions had to be reduced from 2.1x3 m^2 to 1.6x2 m^2. AGARD also had an effect on the design of the supersonic tunnel. AGARD specialists, on a 'travelling seminar', advised to change from a continuous operating facility in the original plans, to a blowdown tunnel. This increased the Reynolds number considerably and it also allowed to enlarge the test section from 0.4x0.4 to 0.8x0.8m^2.

Boel, the newly appointed manager for the HST, had serious doubts about the price agreed in the already awarded contract. He managed to reopen the contract negotiations, reasoning that the price for a 'pound of wind tunnel' should be comparable to the price for a 'pound of submarine'. Eventually, the contract was broken-up and a new contract was awarded to a different company at a much lower price.

The most important change to the original plans was the fact that Boel and Erdmann could convince Van der Maas, the chairman of the Foundation NLL, to increase the test section dimensions of the SST from 0.8x0.8 to 1.2x1.2 m^2. This decision had very significant practical consequences: one and the same model could now be transferred between the two tunnels with very large cost savings for the customer. Since the workload from Dutch customers only (essentially Fokker at that time) was rather limited, it was essential to attract foreign customers to the new high speed tunnels. To this end discussions started with AICMA, the 'Association Internationale des Constructeurs de Matérial Aéronautique' (the 'European organisation of aircraft manufacturers', not including England).

Although there were many more practical problems to be solved (like the pressure vessel, the control valves, the flexible nozzle, the transonic test section) there was one outstanding issue that was highly problematic: the question how to measure the loads on the model: should this be done with an external or with an internal balance? After many studies, travels abroad and in-house developments a conclusion could not be reached. In a report of November 3, 1954, it was stated that *"This decision is more or less a gamble. Apparently, agreement cannot be reached, but the decision has to be taken now."* [6].

III. A big issue: ex- or internal balances

It was clear from the beginning that the choice of the balance system for the new HST had far-reaching implications. Due to the much higher aerodynamic loads, it was far from obvious that the conventional methods used at low speeds could be transferred to transonic or even supersonic conditions. Suspension of the model by wires was not realistic due to the higher loads and interference effects. Hence the model had to be supported by a sting, mounted on a segment with appropriate degrees of freedom to position the model at the required incidence and slip angle in the test section. Such a model support had to be shielded from the flow with appropriate fairings to prevent complicated tare-corrections. This, in combination with all necessary provisions for the balance itself, required a lot of space in- and outside the test section. Consequently, an external balance system had a large impact on the design of the test section itself, the heart of the wind tunnel. Hence external balances could expected to be costly and complicated. But they were based on 'proven technology' and this was a substantial advantage compared to internal balances based on strain gauges. The use of strain gauges for the measurement of stresses in constructions was well known already before the war. But its application in wind tunnel testing on a model support to derive aerodynamic loads was virtually non-existing at the end of the war.

Before 1950 (the freeze of all wind tunnel plans) the 'balance problem' was specifically relevant for the high speed tunnel HST, a tunnel much larger than the planned supersonic facility. But as noted above, the dimensions of the two facilities grew towards each other in time with the crucial decision in 1955 to match the dimensions of the two tunnels such that models could be transferred from one tunnel to the other. Consequently, some form of uniformity in the balance system added an additional requirement.

During the design of the HST both options, in- and external balances were kept alive till about three (!) years before the planned 'wind-on' of the HST in 1957. At that time proven internal strain gauge balances were in fact non-existent apart from some local developments. In the next two sections some of the developments of external as well as internal balances will be discussed to provide insight in the circumstances that finally led to the decision around 1960 to purchase TASK balances.

A. External balances

At the very beginning of wind tunnel testing an external balance mounted on top of the wind tunnel was the most common choice to measure the aerodynamic forces (see Fig.1 to 6). The first balance at NLL (in fact the RSL), inspired by the one used by Eiffel, evolved into the semi-automatic balance of the large low speed tunnel LST as used during and after the war. This system was accurate and efficient and remained basically in use till the tunnel was decommissioned in the eighties with only one essential adjustment: the balances themselves were replaced by loadcells based on strain gauges in 1965.

Not unexpectedly, in the original wind tunnel plans of 1948 it was stated by the then project manager, De Lathouder [7]: *"The tunnel will be equipped with a six-component (external) balance system."* This followed the practice at that time. NLL had always used external balances. The larger supersonic wind tunnel in Peenemünde used a three-component external balance. The original contractor for the HST provided NLL with the complete design report [8] of an external balance originally intended to be used in the 3 m Ø transonic wind tunnel that was planned in Germany during the war at the Luftfahrt Forschungsanstalt Münich (LFM).

Rather than copying what others did, Dobbinga from NLL, who had been involved in the design of the semi-automatic external balance system for the large LST, proposed a very creative approach: the so called 'coefficient balance'. The basic idea was to compensate in the balance design the aerodynamic load (R) with a pneumatic load (P) proportional to the dynamic pressure of the actual flow conditions (see Fig.7). Such a set up would result in an aerodynamic coefficient. In this way load variations due to variations in dynamic pressure could be compensated without loss of accuracy, a kind of *'one size fits all'* philosophy. An experimental test set-up for one component was made and tested (Fig.8). Apparently, the result was encouraging. In a review report of the HST design in 1952 it was stated: *"The models will be supported by a strut attached to an external balance; the development of internal balances has to be pursued"* [9]. In the same year a Swiss company was given a contract to make a preliminary design for an external balance. Also, a preliminary design of the coefficient balance for the HST was made by NLL (Fig.9). This solution was favored by quite a few people, as expressed in a report of 1954 [10]: "*Over the last six years 100.000 Fl has been invested in external balances. NLL is leading in this field, notably because of the coefficient balance."*

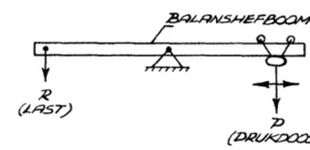

Figure 7 Principle of the 'coefficient balance' (see text).

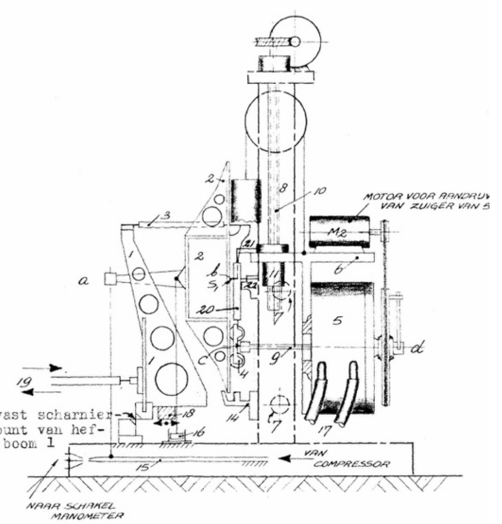

Figure 8 Test set-up for one component of the coefficient balance (1952?).

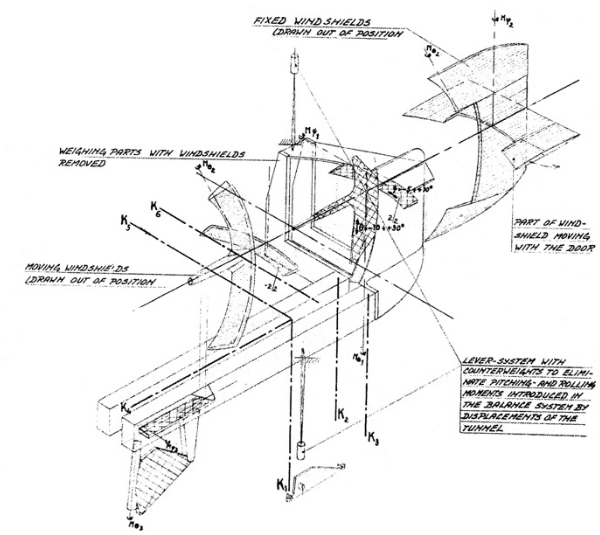

Figure 9 Preliminary design of the external balance and wind shields for the HST (1954).

B. The quest for a good internal balance

In 1948 strain gauges were applied for the first time in the low speed tunnel LST to measure the loads on the aileron of a flying wing model. This test was followed by several other entries till 1951. In the first report of these test [11] it was noted that the use of strain gauges to measure the loads was a novelty for NLL and that is was likely that problems would be experienced. This was the case indeed. In subsequent entries the technique was improved till an accuracy of 1% Full Scale was obtained. A reduction in testing time with a factor of 15 to 20 was claimed. In 1951/52 a test on a large two-dimensional airfoil section was made, also in the LST [12]. The loads on the center section of this model were measured with a number of strain gauges connected to cones that supported the mid-section. Both normal and axial forces were measured. Some claimed that this set-up acted like a temperature gauge. But finally, the results were quite acceptable. In other tests in the LST strain gauges were subsequently used as well to measure the load on control surfaces. But within NLL there was no experience with a multi-component strain gauge balance.

In international contacts, notably through AGARD, the 'state of the art' for strain gauge balances could be gauged. The general impression was not very positive. Accurate measurement of drag and rolling moment proved to be highly problematic. For that reason, some groups proposed 'hybrid' balances: the drag was to be measured in an alternative way outside the strain gauge balance e.g. in the sting or support system. But it was also noted that in the USA external balances were not favored any more. However, this could hardly be understood from the information that was received. It was remarked that each model required a specifically designed internal balance that might take many months to build. For most balance designs strong interactions were reported between the various components. As a result, the data reduction was a huge effort requiring extensive calibrations and complicated and time-consuming calculations.

In 1952 a visit was made to the Technical University KTH in Stockholm where Erdmann had gone after leaving NLR. The group in Sweden was involved in the development of strain gauge balances themselves. However, Erdmann complained [13] that these balances were *"an endless suffering"* and that *"he was longing for a good 3 or even better 5 component balance"*. Despite this negative comment NLL bought in 1953 two 'Swedish Balances' to get 'hands-on' experience [14]. A balance was obtained from MIT as well. There was an urgent reason to do so. The 'Pilot Tunnel (PT), the 1:5 scaled version of the high speed tunnel HST, neared its completion and an acceptance test was planned with the AGARD-C standard wind tunnel model♣.

In 1953, when the new wind tunnel plans were approved by the Government, a special group on 'Strain Gauge Balances' was formed [15]. In the same year the results of a series of tests with the first NLL-made internal balance were reported [16]. Although this balance was named 'Strain Gauge Balance No.1' it was basically a rod with a rectangular cross section on which 8 strain gauges were glued on the outside. Only four components could be measured, leaving drag and rolling moment for subsequent designs. Nevertheless, the experience was essential to get 'hands-on' experience on the use of strain gauges, understanding temperature effects and interactions. A report was written specifying on the design of a calibration unit [17]. The experience so obtained was in fact quite positive.

In 1955 the Pilot Tunnel became operational. A special sting balance was designed to test the AGARD-C model. The model-balance combination that has been tested is still preserved. It is likely that only lift and pitching moment could be measured.

C. The final decision for internal balances

In March 1954 Dobbinga, the man behind the semi-automatic LST external balance (Fig.6) and the designer of the proposed 'coefficient balance' for the HST, wrote the final volume of a series of six reports on 'Tunnel Balance Systems' [18]. It describes the apotheosis of the 'balance problem' including a discussion that took place at that time. Apparently, the new design of an external balance by the Swiss firm (see section A above) was now available. But it was concluded that this design was not acceptable or even worse: it could not be envisaged how to improve it. Even the much favored 'coefficient balance', had to be put aside as the manpower to make this work was simply not available. So basically, the chances for an external balance were not very positive. Not everyone agreed: a few participants at the meeting were still in favor of an external balance.

A report of November 3, 1954 by two instrumentation engineers Prast and Van der Zwaan summarizes all issues related to the instrumentation of the HST [19]. Many aspects were discussed and among these the 'balance question', obviously a very hot issue. It is stated: *"This decision is more or less a gamble. Unanimity in decision-making cannot be expected <u>but the decision has to be taken now</u>."* Apparently, there were still different views how to proceed. The two approaches were so far apart that a good technical compromise did not seem possible.

♣ Note that the AGARD-B and AGARD-C models (without or with a high tail) were proposed by AGARD end of 1952 as a standard model to be used at different scales to validate and compare new transonic and supersonic wind tunnels.

Figure 10 Two newly designed NLL sting-balances used in combination with the AGARD-C models in the Pilot Tunnel (1957).

Less than two weeks later, on November 16, it was noted in a report by the same authors [20] that ". . . *for the time being, strain gauge balances are foreseen, though the possibility to use external balances must be kept open."* Finally the 'knot was cut', most likely by Boel, the project leader of the HST project and the direct superior of Prast and Van der Zwaan. Somewhat later Boel, in a very condensed review of all technical and planning problems facing the HST (36 pages!), wrote just one line w.r.t. the 'balance problem': "*strain gauge balances will be made by the 'group Prast' whenever ordered; a calibration facility will be built."* [21] This decision, much influenced by time pressure and lack of manpower, opened the way to a coordinated effort by NLL to design and construct the required strain gauge balances. This was a very challenging decision. So far only one test with an internal strain gauge balance was planned with a 40 mm ∅ AGARD-C model in the Pilot Tunnel in 1955. And with only a couple of years to go before the first tests in the HST were anticipated.

In 1955 a survey was reported by Prast [22] of internal balances known to NLL, either from literature or through personal contacts. In total 12 balances were discussed, just half of them being able to measure all six components. In the report a 'hybrid' solution was seriously considered to meet the challenge for accurate drag measurements. It was also noted that the solution adapted in the Swedish balance for the drag (a 'bridge' in the center of the balance) was also selected by some of the NACA design's, though in a much more robust way. Based on similar reasoning a number of balances were designed and manufactured at NLL to better understand all ins and outs of the balance design. Two of these balances (Fig.10) have been designed with the intention to be used in the Pilot Tunnel for tests on a ∅ 22 and 40 mm AGARD-C model (Fig.11). These balances were also tested in a Swiss wind tunnel as part of an investigation to understand the transonic characteristics of the newly designed slotted test section for the HST. This experience was essential to design and manufacture larger balances that could be used in the HST and SST. In that respect a balance designed by the 'Cornell Laboratories' (still preserved) might have been a source of inspiration as well. The final design of one of these NLL balances is shown in Fig.12. Basically, the balances are of a mono-block type where independence of the various components is pursued by design. Cones on either side connected the balance to the model and the support sting. These balances were specifically intended to be used on the planned tests with the AGARD-C models foreseen in the HST.

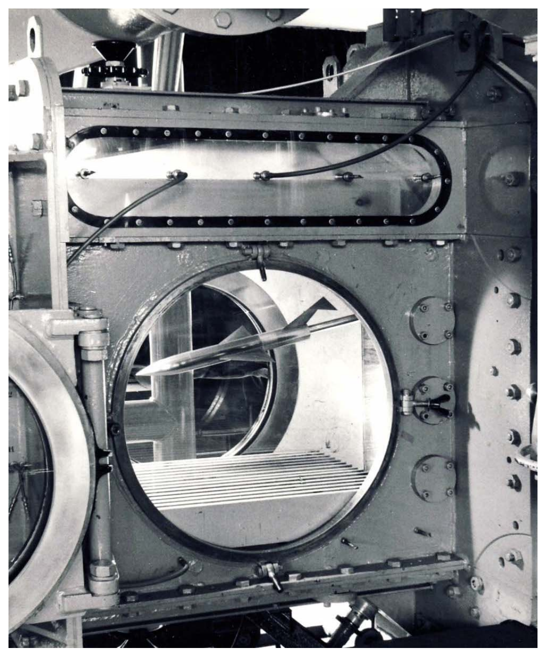

Figure 11 The AGARD-C model installed in the test section of the Pilot Tunnel (1957).

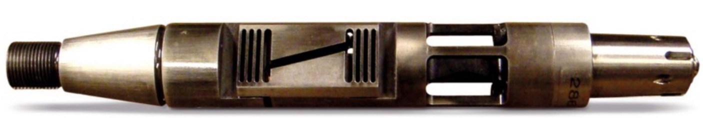

Figure 12 One of the first larger NLL-balances used in combination with the AGARD-C models for tests in the HST (shown without wiring, 1958).

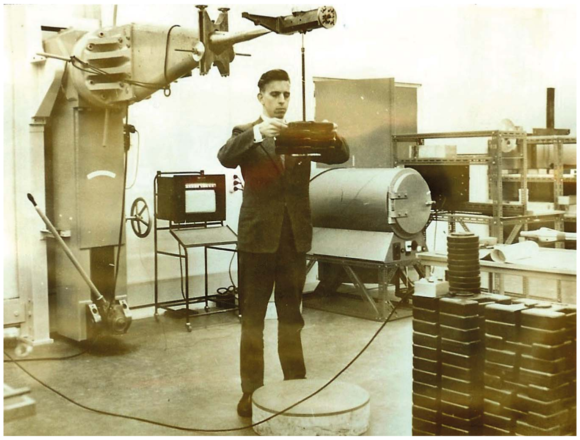

Figure 13 The calibration facility (1958).

A balance calibration facility was ordered from a Dutch machine company (Holleman) in 1957 and commissioned in the course of 1958 (Fig.13). In this setup only one force could be applied at a time to introduce a single force. Two small arms, connected to the calibration body, were used to generate a moment. Test procedures were developed to calibrate the balances including balance deformation with NLL-designed dead-weights. These weights could be stacked on a rod to get an accurate point of application.

On October 10, 1955 the first tunnel segments arrived at the site of NLL in Amsterdam: the actual construction of the HST was begun. Installation of the transonic test section of the HST was foreseen beginning 1957 but delivery problems with the drive system of the tunnel caused an appreciable delay. It lasted till April 1959 that the HST was ready for testing. It was planned to use the standard AGARD models to test out the various systems and to obtain operational experience. Some interested potential users of the HST were waiting to perform tests in the new tunnel. Tunnels of the size of the HST were hardly existing in Europe at that time. In 1955 a contract was signed between NLL and AICMA (see section II). The supersonic tunnel SST with a planned 'wind-on' in 1961, would be part of the deal. Those that were interested to use the tunnel got a 'free ride' to get to know the facility. Hence different customers with different models and requirements were expected to come to NLL in the near future. Were enough balances and balances of sufficient quality available?

IV. The purchase of 18 TASK balances

In the early days of the strain gauge balances it was argued that each model would require a specific balance. This would be both expensive and time consuming. However, in the above referenced report on the comparison of existing balances, it was already remarked that it would be a good idea to have a range of wind tunnel balances of specific diameters 'on the shelf' that would fit the need of the customers. This was exactly the philosophy behind the balances produced by the TASK Corporation.

Figure 14 Some of the 18 TASK-balances purchased between 1958 and 1963.

It is not quite clear how NLL got to know about the TASK balances, a development that was started already around 1951 by Elmer Ward in the USA. TASK is not mentioned in the above-mentioned balance evaluation report of 1955. It is possible that Erdmann and / or Boel learned about TASK-balances on one of their trips to the United States or that Von Kármán made this suggestion. In any case, in 1957 an offer was made by the TASK Corporation to NLL for two balances (2" and a 2½" ∅) for a total price of roughly $ 30.000. The Chairman of the Foundation NLL (Van der Maas) wanted to have a written confirmation that these balances were sufficiently reliable. But the Director of NLL argued *"that the TASK Corporation was a very reliable and accommodating company. Erdmann, who would be visiting the USA very soon, will discuss the issue further."* [23]. In 1958 the acceptance tests for the two balances took place in the USA in presence of Erdmann. Apparently, NLL was satisfied since six more balances were ordered at the end of 1958, to be delivered end of 1959 (Fig.14). In the first year of the operation of the HST (before the official opening !) tests were planned for the French Company 'Sud Aviation' on the Caravelle, a twin-engined passenger plane (Fig.15). This model had been tested before in the USA at 'Cornell Laboratories' and also in France at the Modane S-1 tunnel (a tunnel brought from Germany after the war). For the test in the HST the above mentioned 2½" and 2" ∅ TASK balances were used,

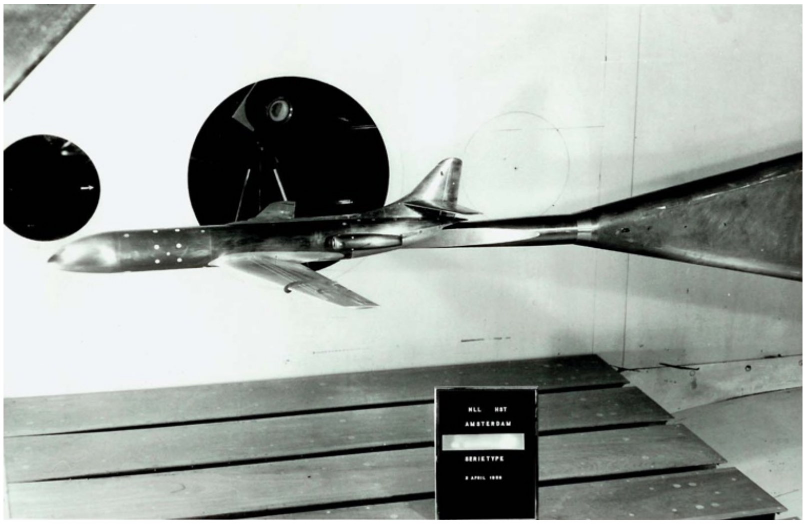

Figure 15 One of the first tests in the HST: Sud Aviation 'Caravelle' in the test section on a TASK balance (1959).

the last one for more accurate drag measurements. This test proved conclusively that TASK balances could easily be exchanged. From the still available test reports during that period it can be seen that some customers used TASK balances, others used NLL balances whereas still others brought their own balance. Also, in 1959 extensive tests on the AGARD-B and -C models of various sizes were made. On January 16, 1960, the HST was officially opened in presence of a delegation of AICMA.

In the meantime, work continued on the supersonic wind tunnel SST. The contract to build this facility was awarded to a Swiss company in 1957. In 1960 the first tunnel parts were delivered on site. Although the construction was finished in 1961 it took another year to start wind-on tests, again with the AGARD models. It is far from obvious that the balances used in the HST would fit the SST tests as well. During an informal AGARD meeting in Stockholm in 1952, Erdmann had already discussed the problem of the start and stopping loads for blow-down tunnels. For that reason, 'proximity plates' were installed in the SST to shield the model.

To support tests in the SST for future customers, a new set of balances was ordered in 1962. This resulted finally in the purchase of a set of 18 Task Balances for HST and SST for an estimated total price of $ 300,000.--, 7½ % of the total investment costs for both tunnels (!). The full range of TASK balances is depicted in Fig. 16. Some balances have a higher range for the same diameter, mainly for use in the SST. The figure is a perfect illustration of the philosophy that '*from the available balances always one balance has to fit the need of the customer'*. This was the main incentive to make this huge investment. In the sixties NLR also designed and built platform balances to be used on half models in the HST. This required a new calibration facility with the possibility to apply larger and multiple forces to better understand and calculate the influence of interactions on all strain gage outputs. This new calibration facility became operational in 1963 to complement the one that was already operational since 1958.

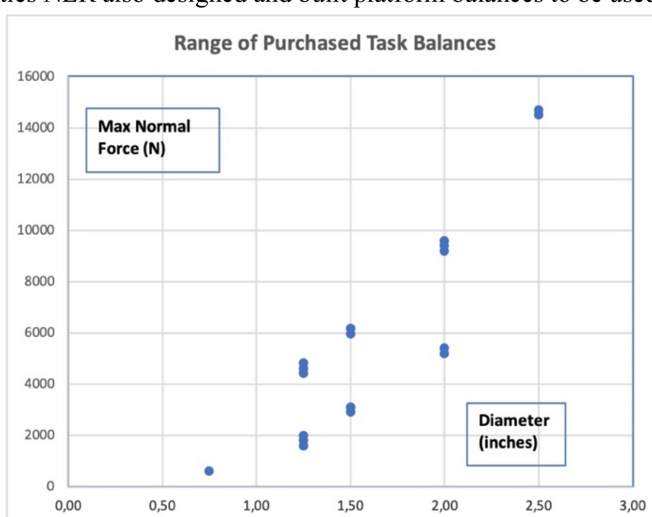

Figure 16 Fig. 16 Range of TASK balances purchased by NLL between 1958 and 1962.

In May 1963 the large Supersonic Wind Tunnel SST was opened officially and ready for its customers. In a brochure of 1959 (!) to inform potential customers of HST and SST [24], it was mentioned that two series of balances were available. Customers could choose a TASK balance for their test depending on the size, loads and accuracy requirements. Alternatively, a balance could also be selected from a range of NLL-made balances, with specific characteristics as far as dimensions and/or accuracy were concerned. And this practice has remained so ever since.

Of course, balances alone are not sufficient to execute wind tunnel tests in an efficient way. In the same brochure, a diagram was shown of the instrumentation of the tunnel. In this diagram, the already realized situation and the situation anticipated for the future had been indicated. In the future setup as outlined, all measurement data are transferred to the computer almost without the intervention of an operator. Data reduction is performed by a computer. A digital computer, based on a Dutch design and built by the English Company 'Stantec', was ordered in 1957. In 1958 this computer, named ZEBRA, a Dutch acronym for 'Very Simple Binary Calculating Apparatus', was delivered. Very soon this computer was too small and replaced by a more advanced one. The Honeywell-Brown pen-recorders (Fig.17) that measured the micro-volts of the strain gauges were digitalized by NLL. On the 'as built' machine an encoder was added to the drive-axis that positioned the pen on the paper-sheet. In this way the pen position could be provided as a binary number. This was subsequently fed into a paper punch machine. In 1964 a memory was added to the data acquisition system of the SST to store 4000 measurement values, collected during the blowdown run, for off-line data reduction after the test. This allowed a very efficient use of the tunnel time.

Figure 17 Honeywell-Brown pen-recorders to measure the balance signals.

Due to the quality of the wind tunnels and the technological improvements in data acquisition, NLL won in 1964 a competitive test involving ONERA (the French sister institute of NLL) and BAC (the British Aircraft Corporation). The main prize was a contract to execute wind tunnel tests on the European ELDO launcher and the Concorde. In the early days of 1960 the Pilot Tunnel and the HST were used extensively for Fokker developments, notably the Fokker F-28 'Fellowship' and the low-supersonic variable sweep fighter 'Alliance', a joint project of Fokker and the American Company 'Republic'. Many European projects passed the HST and SST since that time with the French-English Concorde (Fig.18) and the ARIANA launchers as outstanding examples.

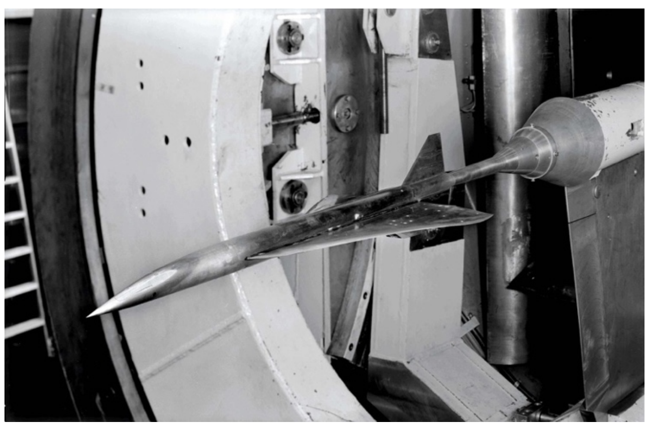

Figure 18 'Concorde' in the SST around 1965.

V. Epilogue

This brings the history of balance measurements for the high speed wind tunnels of NLL in The Netherlands to an end. It describes the delicate balance between technical challenges, innovative thinking and an open mind for international developments.

Since the 60-ies, when the tunnels became operational, there have been many extensions and improvements. The capabilities of the model support system were significantly extended. New hardware was developed for halfmodel testing, engine interference tests, two-dimensional tests, flow visualization techniques, engine testing. Most remarkable are the advances in data acquisition and reduction. In subsequent 'generations', the original system with the Honeywell-Brown pen-recorders, was replaced by more advanced systems that allowed a much higher productivity. In the 90-ies a large upgrade of the HST was realized, notably an increased tunnel height (for high incidence testing), a longer test section and new model supports. After that the tunnels were handed over to the DNW, the German-Dutch Wind Tunnels, a joint operation of NLR in The Netherlands and DLR in Germany. In this way, the pool of know-how available at DLR and NLR could be further deployed for the execution of complex wind tunnel tests. And very recently the optional use of perforated walls in the HST was added as an alternative to the slotted walls for a better performance around Mach=1 and beyond.

Balance development continued as well at NLR. New balance designs were made, notably to increase the accuracy of the drag measurements. Special shaft-balances were developed for high speed propeller tests. But the TASK balances can still be viewed as the 'working horse' for wind tunnel testing. In addition to the 'in house' manual calibration, extensive calibrations are also performed in the Automatic Balance Calibration System (ABCS) in San Diego (USA) since 2015 after trials on NLR internal balances. This system is capable of simultaneously loading all six balance components to obtain a third-order, 6 x 96 balance calibration matrix.

Servicing the TASK balances for major repairs after incidents and requested alterations have always been executed by the TASK company. After their closure, all activities were taken over by the ABLE company. Since the closure of that company, the intellectual property, knowledge and hardware came in the trusted hands of Tony Snyder, owner of Aerophysics Research Instruments. Thanks to his contribution, DNW is able to still use some balances from the initial lot of 18 balances. In the past 65 years the set of TASK balances was expanded by purchasing new ones. Some had to be taken out of active service due to aging or incidents. And a few are preserved for a possible renovation in the future. In the modern world of fast changing technologies and a short lifespan of technical machinery, this situation is quite unique or even pretty sustainable. But the fact that the TASK balances are still used today shows that NLL made a wise decision in 1954 to go for internal strain gauge balances and for the purchase of 18 TASK balances. And it shows equally well the soundness and quality of the original TASK balance design.

Acknowledgments

We would like to thank AIAA and Norbert M. Ulbrich for giving us the opportunity to contribute to this special session to commemorate Elmer Ward and the role of TASK balances in wind tunnel testing. The Heritage Foundation NLR provided all necessary support to collect the bits and pieces that made this story. For those responsible for the design and construction of the high speed tunnels one can only feel admiration. So we finally would like to thank those who contributed to the success of these facilities.

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The history of NLR and its wind tunnels has been described in a few publications [1,2,3]. Information with respect to specific actors can be found in [4,5]. See also the WEB-site of the 'Stichting Behoud Erfgoed NLR 'SBEN: https://www.erfgoednlr.nl/. Most of what has been described above has been taken from NLL reports preserved by SBEN. Since nearly all reports are in Dutch they are refenced by their report number only. They are still available.

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