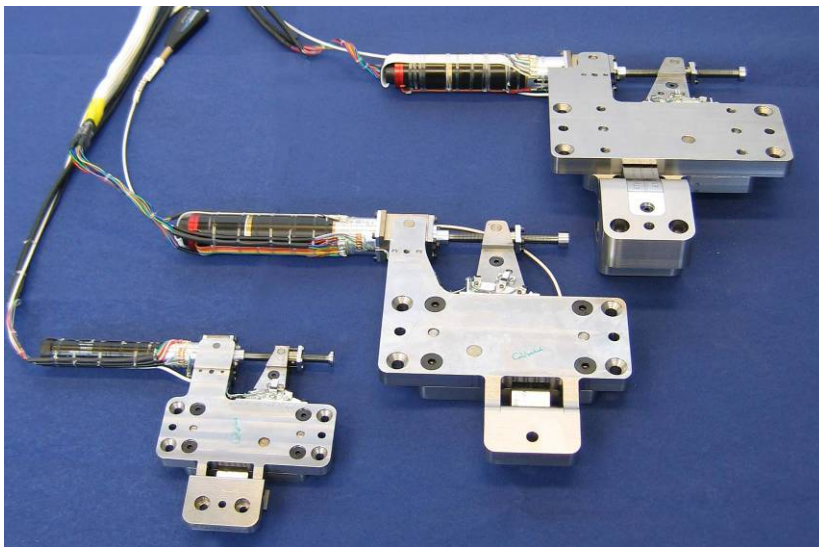




## Executive summary

# Development of Remote Controls for Movable Surfaces of Wind Tunnel Models



*Family of RC systems, based on the same concept, to drive ailerons, elevators and rudder of a low speed model (NLR)*

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Design Methods for Windtunnel  
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This document describes the present status of remote control systems for wind tunnel models, systems that allow to perform model configuration changes from a distance, with the model installed in the wind tunnel test section, without an engineer having to physically enter the wind tunnel. The benefits, advantages and disadvantages, requirements and limitations of remote control systems for wind

tunnel models are discussed. In order to arrive at proven, reliable remote control systems for a wide range of models it is recommended to develop a toolbox of generic, proven solutions, design concepts, for each of the main remote control system components. Finally, the status is discussed of the present experience with remote control systems at various partners of the European Wind Tunnel Association EWA.

**Development of Remote Controls for Movable Surfaces of Wind Tunnel Models**

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NLR-TP-2007-860

## Development of Remote Controls for Movable Surfaces of Wind Tunnel Models



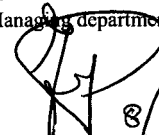
J. van Twisk

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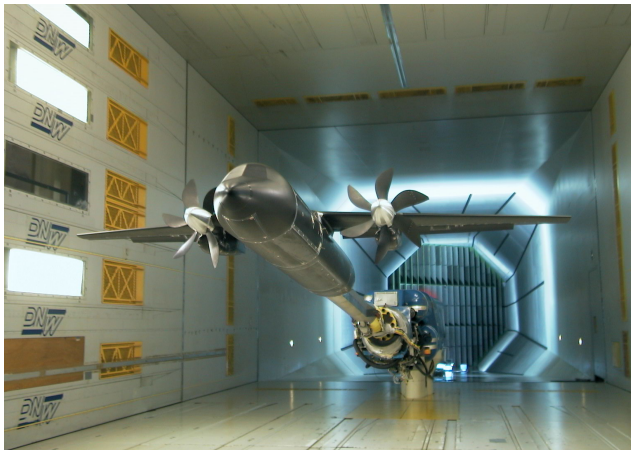
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## 1 Introduction

Remote control systems are commonly used in wind tunnels as part of wind tunnel equipment like for instance wind tunnel support systems, rolling belts, air supply systems, but remote control systems to control parts of wind tunnel models are not so commonly used. Only if the functionality of the model requires remote control to achieve the desired test condition, remote control systems will be integrated in the model. This is particularly so for rotating systems like turbine powered simulators or helicopter rotor drive systems. However, remote control systems to change the settings of movable surfaces like stabilizers, control surfaces and high lift devices are not so commonly used, mainly because the added mechanical complexity makes the model, apart from more costly, also potentially more vulnerable for failure. Still, remote control systems, when properly functioning, offer a tremendous opportunity to increase the productivity of the wind tunnel, thereby decreasing both total cost and lead time of an aerodynamic research wind tunnel test program.



*Fig. 1 Low speed model with remotely controlled turbine powered simulators, driving propellers (DNW)*

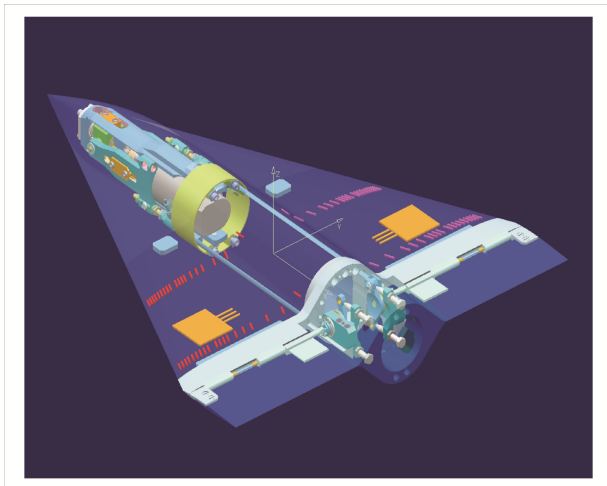
## 2 Why remote control for movable surfaces of wind tunnel models?

Most models require configuration changes when tested in the wind tunnel, ranging from changes of stabilizer settings to control surface settings to high lift device settings.

Up till now relatively few models, requiring these configuration changes, have been built with a remote control system that allows the test engineer to achieve these configuration changes from a distance without having to physically enter the wind tunnel test section.

The major reason seems to be the added complexity (mainly due to space and load constraints) of remote control systems compared with the classic alternative of several sets of brackets, each set for one particular setting.

Still, the advantages of a properly functioning remote control system are so significant that the reluctance of test engineers to apply remote control systems in their wind tunnel models should be overcome by investing in knowledge and experience with respect to design and manufacturing of reliable RC systems.



*Fig. 2 Model with remotely controlled flap system (DLR)*

### 3 The potential advantages of remote control systems

Potentially, remote control systems offer the following advantages:

- **Higher wind tunnel productivity**

Configuration changes through changing a set of brackets will require the physical entrance of an engineer into the wind tunnel test section to remove one set of brackets and to install another set. Depending on the user friendliness of the model this will take some time, but closing down and speeding up the wind tunnel will require even more time. Depending on the accessibility of the wind tunnel this can be significant. Especially for pressurized wind tunnels and, worst of all, cryogenic wind tunnels, much time will be lost when a model configuration change has to be made. With remote control much time can be gained if this physical entrance into the wind tunnel test section is not required to achieve the desired configuration change. With remote control the configuration changes can be achieved within (tens of) seconds without the need of changing the wind tunnel test (flow) condition, such that the productivity of test runs can be very high. This will either save considerable test time (and money), or within a given test time will produce a lot more test data as without remote control.

- **Better model functionality**

Remote control systems allow any intermediate control setting, whilst with brackets only a limited number of discrete settings, to be defined well before the test execution, will be possible. To get a good coverage of the full range of settings it is not uncommon that some ten settings per control surface will be required. For a set of (two) elevators, each mounted to the horizontal stabilizer by two brackets, this amounts to some forty brackets alone. For models with flaps, left and right, inboard and outboard, two or three brackets per flap, this can also easily amount up to some forty to fifty brackets. For a low speed full model a total of some 150 brackets will be the result, which is a significant cost driver for the model. A similar model with remotely controlled control surfaces should not be much more expensive and will have a better functionality. Also pre-programmed, automated functions will be possible, as well as real position/angle measurement under load.

- **Lower cost**

For both of the above reasons, the total cost of the wind tunnel test program, including the model, will be lower for a model with remote control as compared with a model with brackets to set the control surfaces. Only for small low speed programs with limited configuration changes the cost saving will be small, but for large programs, especially in pressurized wind tunnels, it will be significant.



*Fig. 3 Rear fuselage of model with remotely controlled elevators and rudder (NLR)*



## 4 The potential disadvantages of remote control systems

Of course, the added complexity due to remote control also has some potential disadvantages:

- **Longer model lead time**

Unfortunately, the development of a dedicated remote control system for a specific model will require more time than a set of straight forward brackets. Design, manufacture, assembly, testing and calibration of the remote control system will add some weeks to the development time of a typical full model. However, this should largely be compensated by the higher production of the test program.

- **Higher risk for malfunction**

It is undeniable that remote control is more complex than straight forward brackets, but when properly designed and based on proven concepts, the risk of mechanical problems will be minimal. Also, if desired, it will always be possible to add a relatively simple mechanical back-up for a limited number of fixed settings.

- **Limited feasibility**

The feasibility of remote control systems strongly depends on the maximum aerodynamic loads on the relevant control surface and the available space for the required remote control system. Especially for highly loaded transonic models, the combination of high loads and very limited space can reduce the feasibility of remote control systems significantly. For cryogenic models this will be even worse.



*Fig. 4 Cryogenic model with remotely controlled horizontal tail plane (ONERA)*

## 5 The generic remote control system

A remote control system will consist of a number of components, working together as one complete system. These components are the following:

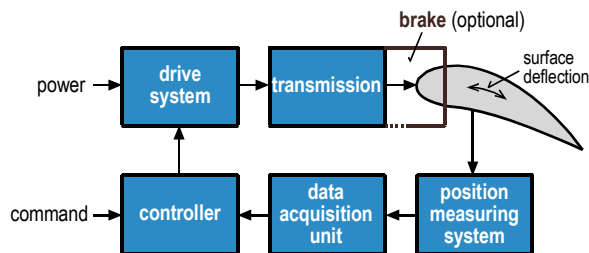


Fig. 5 Generic remote control system

- **Controller**

A controller will be required to convert the steering command (lever, push button, dial, etc) into electric signals to the motor drive system. In case of a closed loop system, the controller also receives the output of the position sensor of the position measurement system to correct the actual position for the selected position. No further information is given in this article on the required controller.

- **Motor drive system**

Although in principle the type of drive system can vary from electric to hydraulic to pneumatic, the most common principle is electric. Tests have been done with miniaturised hydraulic actuators, but the results up till now have not been too promising. Electric motors usually come together with a suitable reduction gear box to provide the required torque and also with a resolver for position indication of the motor. There are several suppliers of these electric motors.

- **Transmission system**

For each RC system some kind of transmission system will be required to convert the rotary or linear output from the (electric) motor into a rotary or linear movement of the model component. Especially when the RC system has to be installed inside the wing or tail plane, the design of the transmission system will be the most critical part of the complete RC system.

- **Brake system (optional)**

If the transmission system is not self-braking under full load, a separate brake system will have to be added. Preferably, this should be integrated with the drive system. For this reason, it adds complexity to the system and should be avoided if possible.

Also, in case of very highly loaded RC systems, the transmission system may become too complex or even physically impossible and thereby unfeasible. To alleviate the complexity

of the transmission system, a brake system can be added to hold the model component in the selected position at maximum load. By accepting the limitation that the selection of the desired position of the model part is only possible at relatively low load conditions, the design of the transmission system can be simplified significantly. For highly loaded RC systems this approach may be the only alternative to achieve a properly functioning system.

- **Position measurement system**

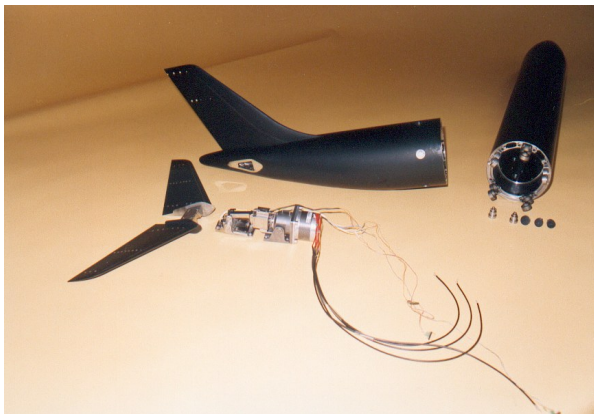
It is of utter importance that the exact position of the driven model part is unquestionable throughout the entire setting range and at all load conditions. Therefore, the position measurement system shall be independent from the RC drive system. Various off-the-shelf sensors are available on the market, but claimed accuracies shall always be verified.

Depending on the location, movement of the model component and required travel, a suitable sensor shall be selected and integrated in the RC system in such a way that the output of the sensor will not be affected by parasitic effects due to the varying loads on the system. In general, the sensor accuracy will always be negatively affected by these installation effects to some degree, which shall be minimized by careful design.

In some cases also the output of the resolver of the electric motor can be used as a suitable position signal, but only if the transmission system is very direct, without any play or hysteresis and without the mentioned parasitic effects.

- **Data acquisition unit**

A data acquisition unit will be required to receive, convert and record the output signal of the position indicator. No further information is given in this article on the required data acquisition unit.



*Fig. 6 Remote control mechanism for horizontal tail plane of cryogenic model (ONERA)*

## 6 Requirements for a properly functioning remote control system

To ensure that the desired remote control system will function properly and reliably throughout a reasonable test period, the design will have to comply with the following requirements:

- **Available space**

The smaller and more highly loaded the model, the more difficult it gets to design the required RC system such that it will fit within the aerodynamic lines of the model and at the same time does not weaken the surrounding structure to such an extent that the structural integrity of that model part is at risk or elastic deformation becomes too much. This is particularly relevant for an RC system that has to be mounted inside a wing or stabilizer.

- **Loads on model parts**

Obviously, this together with the space constraint, is the most critical factor for the feasibility of an RC system. Without a clear view of the maximum loads that can be expected on the to be driven model component, a proper design of the required RC system will not be possible. Possible model movements or vibrations leading to significant g-levels shall also be specified.

- **Self braking or with additional brake**

Once set in the correct position, the RC system shall be able to hold the set model component into that position, also under full load or at vibrating conditions. If the RC drive system is not capable of doing so, a separate brake system should be added. Preferably this brake should be active (“on”) when powerless and passive (“off”) when powered to ensure correct functioning during test runs. In this way, the RC system will be intrinsically safe and will not cause possible EMC when model test data is recorded

- **Temperature range**

A normal temperature range to be expected in the wind tunnel will be from some 0 °C up to 60 °C. Usually, this will not be a problem. Lower temperatures as common in icing wind tunnels or, even worse, cryogenic wind tunnels, will lead to problems if no specific care is taken in the choice of materials, motors and sensors. Available motors and sensors for cryogenic conditions are very limited. A way around this may be heating of various critical RC components, but this will increase the size of the RC system. At the other hand it is quite obvious that especially for cryogenic wind tunnels, remote control systems provide a very effective means to increase the productivity of this kind of tunnel, thereby lowering the cost of cryogenic wind tunnel testing considerably.

- **Setting range**

The required setting range for the to be driven model component is an important parameter in the design of the RC system. For fully rotary or fully linear transmission concepts it will soon be feasible to accommodate a large setting range, but for linear-rotary concepts the maximum angular range may be limited to some 60 degrees.

- **Required setting accuracy and repeatability**

The setting accuracy will depend strongly on the friction and hysteresis in the RC system, as well as on the controllability of the motor drive system, both in speed and inertia behaviour. A variable speed will offer both acceptable setting times and acceptable setting accuracy. If the speed is fixed, an optimum shall be found between these two. This will also depend on the application: for some applications it is not so important to set the model part accurately in a predefined position as long as the position is measured at all times, for other applications it is of utter importance to do so. In any case, the characteristics of the RC mechanism shall be repeatable.

- **Position indication**

For any RC system it is important in all cases to know exactly and at all times what the position of the driven model component is. Therefore an angular indicator accuracy of at least 0.1 degrees or better is required, independent of the loads on the driven model component.

- **No play and minor hysteresis**

These requirements are somewhat contradictory: play can be avoided by using small tolerances for moving parts, unfortunately causing a relatively high friction level, whilst high friction causes hysteresis. Once play has developed, it will rapidly increase due to vibrations.

Play in the RC system will not enable accurate positioning of the driven model part, and will not ensure a fixed position once set. Thus play should be avoided in all cases. Only if the required positioning accuracy is limited, and if there is a brake to hold the model part in position once set, some play could be acceptable, thus relaxing the requirements for the RC drive and transmission system.

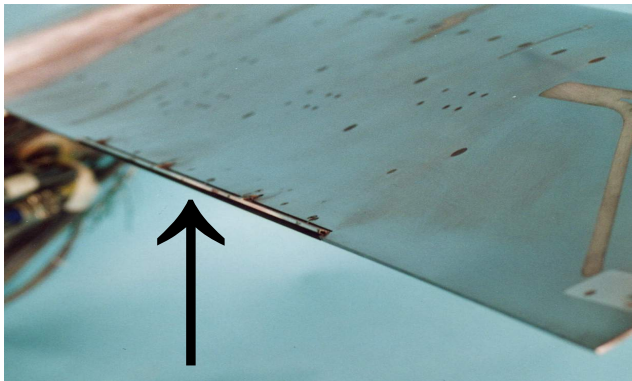
Hysteresis will be unavoidable due to friction in the RC mechanism. However, it should be limited as much as possible by choosing an optimum level of friction. Hysteresis will decrease the setting repeatability, but can be eliminated if the required setting angle is always approached from the same side. Also, if the position sensor measures the setting of the driven model part as direct as possible, hysteresis of the RC mechanism becomes less important.

- **Acceptable wear**

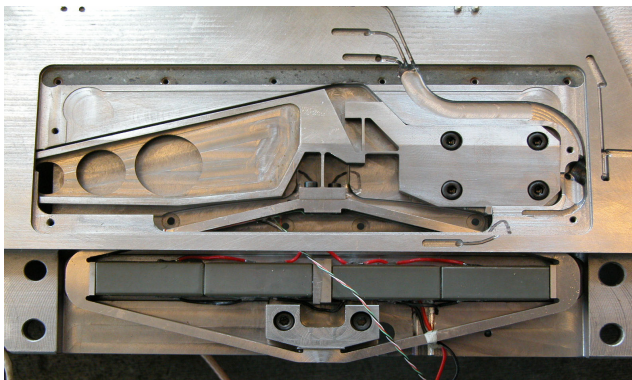
The requirement for no play inevitably leads to a fairly high friction level of the transmission system, and thus to significant wear thereof. This may not lead to an unacceptably fast deterioration of the RC system. It shall have a life of at least one wind tunnel test campaign, say some 100 test hours, without requiring intermediate overhaul. It will always be advisable to check the RC system characteristics before starting a new test campaign, and to perform necessary maintenance if needed.

- **Allowable deformation under load**

Especially when highly loaded, any mechanical RC system will deform elastically to some degree. This deformation should be limited as much as possible by designing an as stiff as possible RC mechanism. If a brake has been installed to fix the position of the driven model component, this requirement will only apply to the brake system itself. Without a brake system, and if monitored continuously, the position of the driven model component can be corrected manually or automatically (by a closed loop control system). This can only be done if the RC system is strong enough to allow positioning under full load.



*Fig.7 Remotely controlled wing trailing edge (ONERA)*



*Fig. 8 Piezo-electric drive system to drive wing Trailing edge (ONERA)*

- **EMI requirements**

The RC system, in particular the motor drive system, should not cause any electro magnetic interference to the instrumentation in the wind tunnel model. If unavoidable, care should be taken that no measurements are performed whilst the motor drive or brake system is active.

- **Proper calibration**

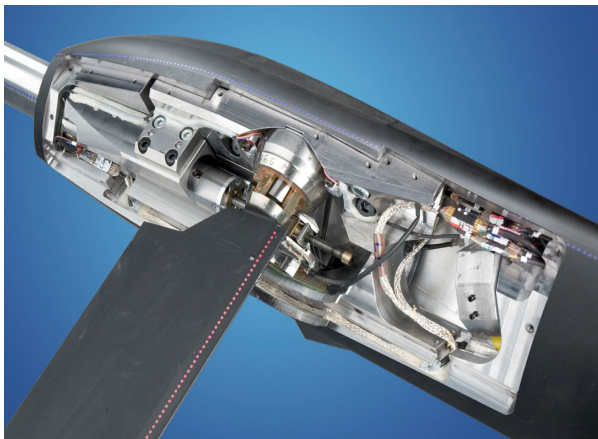
A proper calibration of the position measuring system, preferably when installed in the model, is of large importance for the accuracy of the RC system.

The calibration reference system shall be at least one order of magnitude more accurate than the RC position measuring system. Care shall be taken that the calibration sensor measures the relevant surface setting in an undisputable way. To avoid any misunderstanding, the definition of the surface setting shall be clear to both the RC manufacturer and the customer. Deformation under load shall also be considered. A representative reference plane shall be defined, and, if not readily available, provisions shall be added to make it available.

## 7 Limitations of remote control

From the above it can be concluded that the feasibility of a remote control system for a specific customer requirement will always be limited by a number of factors, being:

- The available space inside the model
- The maximum loads levels on the model components to be driven by the RC system
- The required operational temperature conditions
- The amount of acceptable hysteresis in the RC mechanism
- The required setting accuracy and repeatability
- The amount of acceptable elastic deformation under load
- The limited life of the RC mechanism due to frictional wear
- The EMI aspects



*Fig. 9 Model of air refuelling boom with remotely controlled weighed set of wings (NLR)*

Dependent of the customer requirements these limitations will allow or prevent the feasibility of a remote control system for a certain model. Specific requirements may need specific solutions. New solutions will require adequate testing and evaluation, probably modification, before being suitable for industrial application. The available time for development of the model will usually not allow that (disregarding financial risks). Therefore, it is advisable to compose most remote control systems out of existing, proven RC components.



## **8 The toolbox approach to remote control**

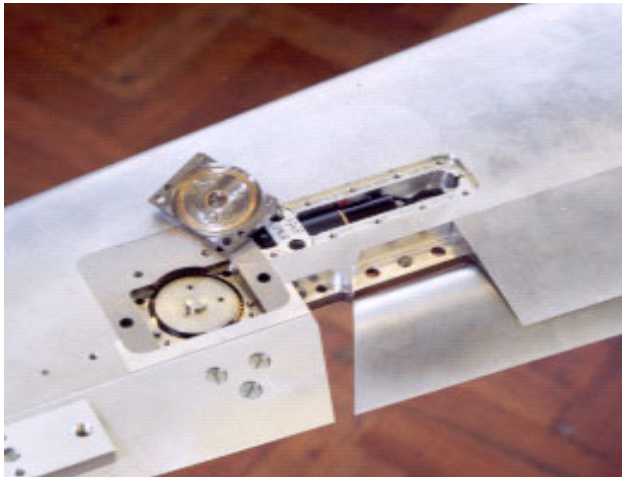
Various manufacturers of wind tunnel models have varying experience with remote control systems, but their experience appears to be limited and quite random. Few of them have done systematic development with alternative concepts. Each RC system appears to be a custom built solution for a specific model requirement, leading to a unique solution, tailored for that specific model. Consequently, no generic concepts, being applicable to most wind tunnel models, appear to have been developed.

This situation has been so for many years, not convincing potential customers for good reasons (bad experiences) that remote control for wind tunnel models is a safe way to go. In fact, potential customers, industrial customers in particular, have been very reluctant up till now towards applying (unproven and thus unreliable) RC systems in their models, and rightly so. Also, the average model builder is a designer and manufacturer of stationary mechanical structures (i.e. models) rather than of kinematic mechanisms, thus by nature he is not the obvious developer of these mechanisms. Without sufficient funds made available for systematic research and development into remote control systems, this situation will not change quickly.

The way to arrive at proven, reliable RC systems for a wide range of models is to improve experience in a systematic way to arrive at generic, proven solutions for different requirements for each of the four mechanical RC components as mentioned above. For each of these four components, alternative concepts shall be developed for different applications. Thus, a toolbox can be filled with generic, proven solutions, design concepts, for each of these components. Consequently, the optimum RC system for a specific model will be the optimum choice of released tool box components, as a complete system complying with the RC requirements for that model. Thus, the toolbox approach is strongly recommended as the right way to arrive at reliable, low risk RC systems fitting within the tight time-schedules that are demanded by industrial development (wind tunnel) test programs.

An example of this toolbox approach is the NLR development of an RC system to drive the ailerons of a low speed model. Since the available height in the outboard wing is very limited, the transmission component of the RC system has to be kept relatively flat. As a first concept, a drum type transmission was developed, built and tested. After improvements, a second generation version was made available for application in a low speed Dornier 728 model, which functioned reasonably well. After further improvements, a third generation version was applied for a low speed Dornier 928 model, functioning to full satisfaction of the customer. This model was also supplied with stabilizer, elevator and rudder RC systems, all being different and unique. The resulting wind tunnel productivity of this model during a large test campaign in the

ONERA F1 wind tunnel was claimed to be very high (some 80%!) by the customer, proving the large lead time and cost reduction potential of RC systems



*Fig. 10 Remote control system to drive aileron, drum type (NLR)*

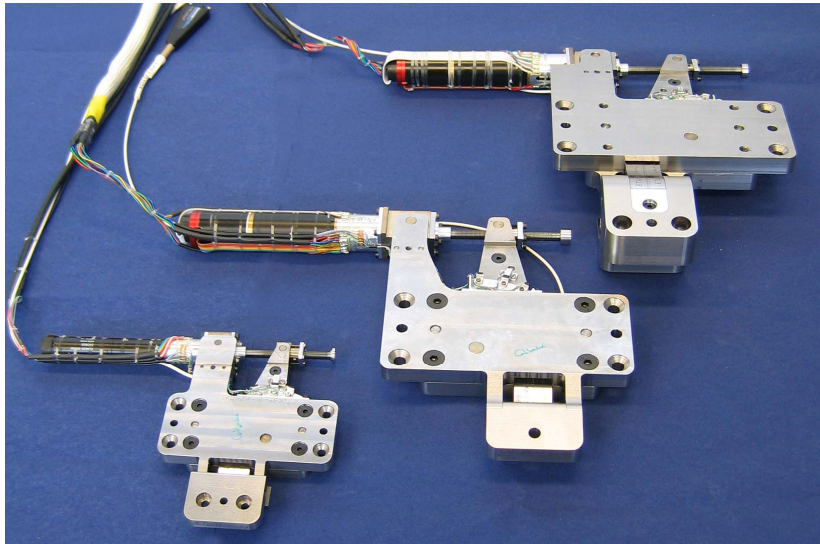
Due to setting range limitations of the drum type aileron RC system, making it unfit for elevator or rudder applications, a new development was started, based on a different transmission concept. This concept was tested and improved several times. A third generation was miniaturized down to transonic dimensions, but the elastic deformation under full load turned out to become quite high. In that situation it may need a brake to add sufficient stiffness.

Soon after, DNW was faced with an industrial customer, that considered the large test program in the DNW Large Low speed Facility, which they had envisaged with a model of themselves, as too expensive. DNW came up with the proposal to reduce the cost of the wind tunnel test program through adding NLR built remote control systems to drive the ailerons, elevators, rudder and horizontal tail plane of this model, thereby reducing configuration change times (and thus wind tunnel cost), resulting in significantly lower total cost.

NLR designed and build the six RC systems, all of which (except the HTP) were based on the new concept that had been tested thoroughly. NLR also specified the required model interfaces, performed the RC integration in the model and the calibrations, assisted by DNW.

Thus, a family of 5 RC systems was built to drive all control surfaces of one model, based on the same toolbox components. All systems performed perfectly and wind tunnel productivity was as high as expected.

This would not have been possible if it would have been a new development, not matured through extensive testing of prototypes. It proves that the toolbox approach results in reliable, low-risk RC systems.



*Fig. 11 Family of RC systems, based on the same concept, to drive ailerons, elevators and rudder of a low speed model (NLR)*

## 9 Remote control systems development within EWA

In September 2004 representatives of 8 European manufacturers and users of wind tunnel models came together within the context of EWA, the European Wind Tunnel Association, a European Network of Excellence, funded by the European Community for a period of five years (2004 – 2009). This EWA group was tasked to come up with proposals for joint research in the field of Advanced Wind Tunnel Manufacture. Apart from various other subjects, a remote control system for wind tunnel models was chosen as a suitable subject for joint research.

A number of EWA partners have experience with designing and building RC systems for wind tunnel models, some more than others.

The applications can be summarized as follows:

- Flight control surfaces like elevators and rudders with (most of) the RC system in the rear part of the fuselage of the model
- Flight control surfaces like ailerons with the RC system in the wing
- High lift devices like flaps and slats, limited to hinged surfaces
- All moving surfaces like stabilizers, canards, vanes, speed brakes
- Various others like trailing edges, rotating bodies, store release mechanisms.

RC systems for translating (traversing) high lift devices like flaps have been studied but not realised as yet.

Every EWA partner acknowledges the fact that expanding the knowledge of and experience with remote control systems for wind tunnel models is very desirable. For high speed models, the challenges are considerably more severe as for low speed models, mainly due to the space and load limitations as mentioned before. For cryogenic models, transonic in particular, the low temperature requirement adds another challenge of different nature. Therefore, the toolbox development should go from low speed models to high speed models to cryogenic models, each type of model with its own complexity, requiring different design concepts.

Various project proposals on remote control have been submitted by the EWA advanced model manufacturing group, two of which have been rewarded up till now:

- The development of a remote control aileron drive system for a transonic model of ARA-TWT or DNW-HST size, fitting within the aerodynamic lines of the wing.

For this project three different concept designs were made by three of the partners of this advanced models group. The most promising one was selected to be build, tested and evaluated. This project will be completed by the end of 2007.

- The development of a non-contact positioning measurement system for the same transonic aileron RC system, also fitting within the aerodynamic lines of the wing. Two of the partners studied four different concepts. Only one was proven to comply with the requirements, and was selected to be build, tested and evaluated. This project will also be completed by the end of 2007.

These two projects cover three of the four mechanical system components of a generic RC system for a transonic, ambient model only. For the fourth component, the brake system, a project proposal has been submitted as well, and may be rewarded for a later phase in the EWA program.

These EWA projects on remote control components cover a limited part of the RC toolbox. These studies on RC for transonic models were selected because the available space for a remote control system in the wing of such a model is very limited, and the loads on the model fairly high, which makes these projects very challenging. Since the EWA funds for systematic research in the field of remote control are fairly limited, only part of the toolbox can be developed. However, it is an important step in the right direction.

## **10 Conclusions**

Experience with the development of remote control systems for wind tunnel models is limited and random. Each RC system appears to be a custom built solution for a specific model requirement, leading to a unique solution, tailored for that specific model. Consequently, no generic concepts, being applicable to most wind tunnel models, appear to have been developed. It is advised to perform a systematic development of alternative RC system concepts. From these concepts it is considered feasible to arrive at a toolbox of generic, well proven, reliable RC system components, supplying the major elements for most RC systems as required for wind tunnel models.

The first steps into this direction have been made by individual model builders and also by the EWA task group on Advanced Model Manufacture.