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# MANAGEMENT, ARCHIVING AND PROVISION OF AERODYNAMIC AND AEROELASTIC DATA - A NEW DATABASE CONCEPT

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**Abstract:** In order to share and to improve the usage of high-quality measurement data, a new web application called "AeDb" (***Ae**ro**e**lastic **D**ata**b**ase*) in combination with a measurement database is presented. AeDb can be used to manage, archive and provide aerodynamic and aeroelastic wind-tunnel data, numerical simulations, and other project related files such as videos and papers. When flowing through the database the data can be filtered and searched, for example to investigate measurement points with specific parameters. In addition an easy access to the data via Python or MATALB is included as well as the possibility to intuitively generate a new measurement campaign. It also enables a more effective and user-friendly execution of experiments through measurement automatization what in detail means that a measurement point only can be triggered if all persons are "ready" (multi-person-agreement). After the measurement the data gets automatically uploaded and synchronized to the database. For this purpose, this paper first describes how measurement campaigns have been prepared and executed in the past. Afterwards, the requirements that arise due to the age of digitalization and the increasing amount of data will be discussed, followed by a description of the AeDb. Finally, an overview of the used hardware and software is given.

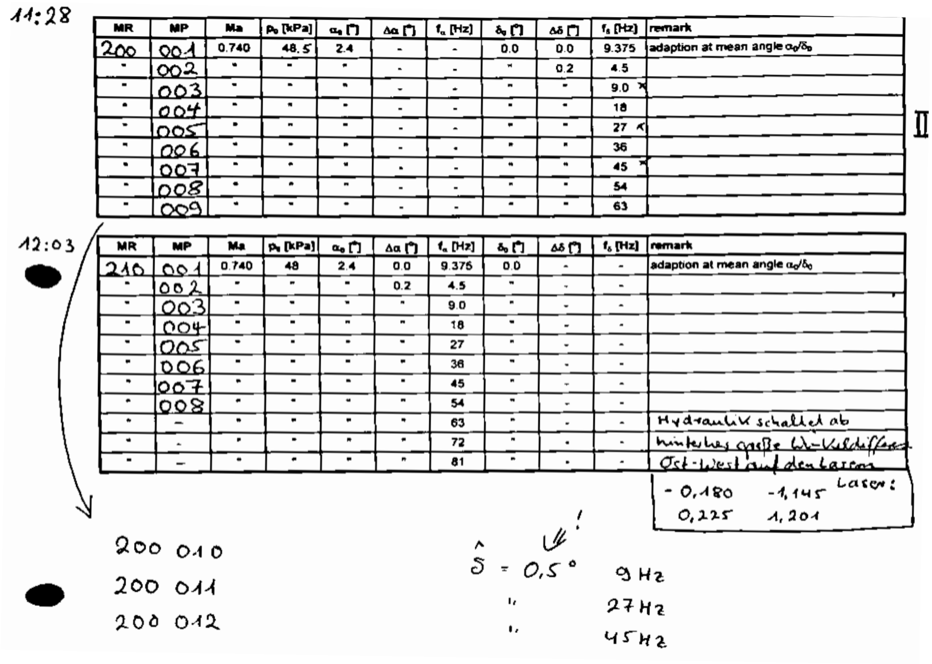
## 1 INTRODUCTION

In the 21st century, data is considered one of the most important commodities [1]. Data management plans are now required by many funding bodies as part of the funding application [2] and present new challenges for data management of aerodynamic and aeroelastic experiments. But along with the development of new measurement techniques, the size of the recorded data grows. While in steady experiments only individual time points were read and stored, for aeroelastic measurements entire time series are mandatory. The data size is increasing even more due to rising sample frequencies and an increasing number of sensors. Today, research data management is an important basis for the scientific community to collect, prepare, secure and make available research data for subsequent use.
The DLR Institute of Aeroelasticity already has large amounts of high-quality measurement data, which are used intensively at the institute and in the scientists community like the COSDYNA [3] (***C**ontrol **S**urface **DYNA**mics*) experiment, the famous MP77 test case [4] and others [5,6,7,8]. Thereby the data is stored on the AMIS (***A**nlage zur **M**essung **i**nstationärer*

***S**ignale; german for: Plant for the measurement of unsteady signals*), which is also used for the acquisition and analysis of large amounts of steady and unsteady wind tunnel and flight test data. For this purpose, there are 960 analog and 162 digital input channels available to the system. But, so far, there is no smart way to share this data with the community. There are also other challenges in managing and using the data. For example, it is easy to lose the overview or see a relation to another dataset. It is therefore not uncommon that scientists spend more time searching for and processing measurement data than it is actually desirable. It may also happen that work that has already been done is forgotten in the course of time. The result in turn is that other scientists make research on the same problem again.
In the course of the increasing amount of measurement data and to promote the subsequent use by the aeroelastic community, the DLR - Institute of Aeroelasticity in Goettingen has set itself the goal to develop a new database environment. It is intended to make it possible for scientists to search quickly and intuitively for projects that have been worked on at the institute. That in order to use the data and knowledge for their own project, and later to feed the database with their investigation results. This makes the database much more than just a pure measurement database, because project related papers, research reports, FE models, CAD data, etc. will be stored in the database. This not only promotes collaborative research, but also ensures that future generations have access to the archived knowledge.

## 2 HOW MEASURMENT CAMPAIGNS WERE CARRIED OUT IN THE PAST

The execution of an aeroelastic wind tunnel experiment involves not only the purely scientific side, but also an extensive experimental side. This includes, for example, the preparation of the experiment, where various electronics have to be installed. In addition to all the sensors, the entire measuring equipment, such as the measuring server and the measuring computer, must be set up and wired. Since no experiments are alike, this is by no means a routine task. What causes that problems are often only discovered while the experiment is being set up, and solutions have to be found in the shortest possible time.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| MR | MP | Ma | $p_0$ [kPa] | $\alpha_0$ [°] | $\Delta\alpha$ [°] | $f_\alpha$ [Hz] | $\delta_0$ [°] | $\Delta\delta$ [°] | $f_\delta$ [Hz] | remark |
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Figure 1: Measurement sheet of MS 200 and MS 210 of the COSDYNA IV campaign

To the complex measurement preparation also belongs the creation of measurement plans. Up to now, this has been done mostly in tables, in which the individual measuring points are described. However, this needs more time than necessary. To illustrate this, Figure 1 shows an example of a measurement plan of two measurement series of the COSDYNA IV project [3]. In order to relieve scientists, AeDb already starts here. In the future, all measurement plans will be created automatically with just a few clicks by defining an auto-increment with its start and step size. Thereby the measurement plan can be accessed digitally at any time, but of course the measurement plan can also be printed. By looking at Figure 1 further and considering that this is one of several hundred measurement sheets, it becomes obvious that important comments, spelling mistakes, etc. can easily be overseen. Exactly here AeDb offers the next point of contact, thus the measuring points can be sorted (out) and commented right away. Since these changes are immediately synchronized with the database, the probability of overlooking important information during the measurement evaluation is reduced.

## 2.1 Structure of a measurement campaign

All experimental parts of a projects on the institute are subdivided into different measurement campaigns. Each campaign (VR) is split into several measurement series (MS), which have a constant measurement parameter, e.g. Mach-number, whereas other parameters are varied, e.g. the angle-of-attack. Thereby a measurement series consists of several measuring points (MP).
Each measuring point in turn, includes various measurement techniques. The data of these techniques can be individual measured parameters, time series, videos, etc. In many experiments, measurement technologies and sensors like piezoelectric balances, pressure transducers, accelerometers, etc. are involved. These in turn cannot always be stored as a single file. Thus, it is common to end up with three or four separate files for a single measurement point. If this is extrapolated for an average project (one VR), with about 100 MS's and 20 MP's each, it can reach easy up to 8000 files of measurement data. With several experiments per year, the problem quickly becomes apparent.
To illustrate this, Figure 2 shows a typical data-set of one VR with eight of its belonging measurement series which belong to the same investigation objective. For each MS the incoming Mach-number ($M_\infty$) was set constant and the angle-of-attack (AoA) was changed. Thereby for each AoA, data was recorded in the form of a time series and stored as measurement point. For example, the forces of a piezoelectric balance can be used to calculate the aerodynamic lift ($c_l$) and drag coefficients ($c_d$). After the aerodynamic coefficients have been averaged over time, typical Lilienthal polars can be drawn, as shown in Figure 2.

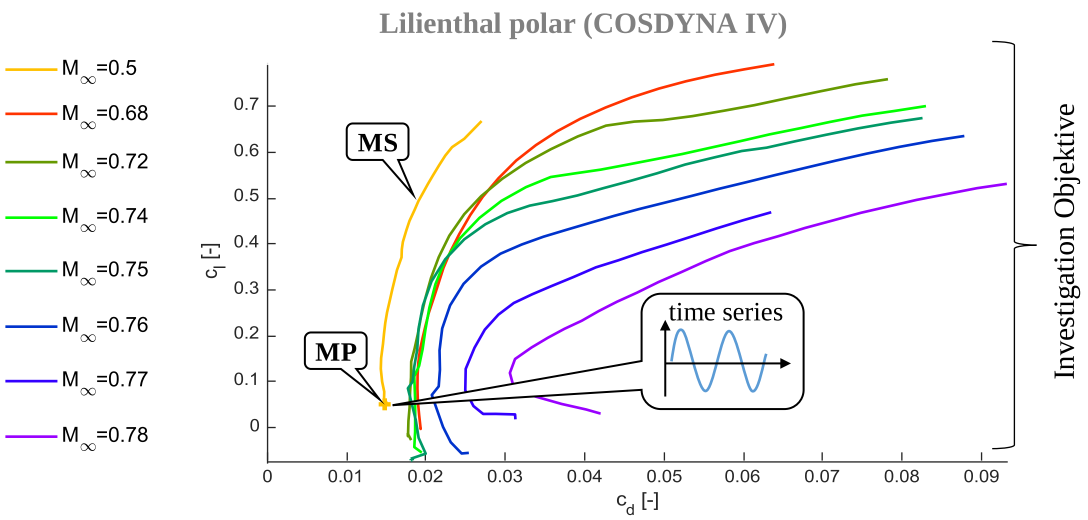


Figure 2: Measurement data of one investigation objective [3]

## 3 WEB APPLICATION FOR MANAGING, ARCHIVING AND PROVIDING AERO-DYNAMIC AND AEROELASTIC DATA

It is not unusual to use measurement data of projects that are more than ten years old. Scientist may not remember all details of the experiment thus the compilation of all measurement data can take several months. This in turn proves to be even more time-consuming if the scientist was not involved into the experiment.

### 3.1 Tasks and functionalities of the application

With AeDb, scientists have access to all measurement data of any experiment. With the help of a search function, they can also evaluate measurement data across experiments and all additional information describing the experiment and data. For example, if a new phenomenon is discovered and it is to be investigated whether this phenomenon is unique, it is possible to quickly search for experiments with similar parameters. For this purpose, the previously mentioned data structure is merged in the database. Figure 3 a) shows a listing of all experiments (=Projects), Figure 3 b) shows the measurement series of one project, and Figure 3 c) illustrates its measurement points (comparative to Figure 2).


Figure 3: Database tables

#### *3.1.1 Searching*

The projects in the database can be examined in two ways. On the one hand, it is possible to search for keywords in the current table, or on the other hand to search across tables for specific parameters. Figure 4 c) shows therefore an example of a search in all projects where the Mach number is equal to 0.5.

By searching for a specific experiment, not only the measurement data is displayed, but also various previously published studies and papers, numerical simulations, models, videos and much more (see Figure 4 a)). Thereby the database is written in such a way that a scientist can upload or link own data and research work to the project in order to give other researchers access to the own results. In addition, it is also possible to evaluate individual measurement points directly in the application. For this purpose, a Matlab function is called that plots for example the pressure distributions $c_p$ over the normalized wing chord x/c (see Figure 4 b)). The plot is then returned to the client as a scalable vector graphic (*.svg*). In this way, scientists and external customers can quickly see whether the data is of interest. Thereby AeDb can also be used as a central interface for cross-project data and files.

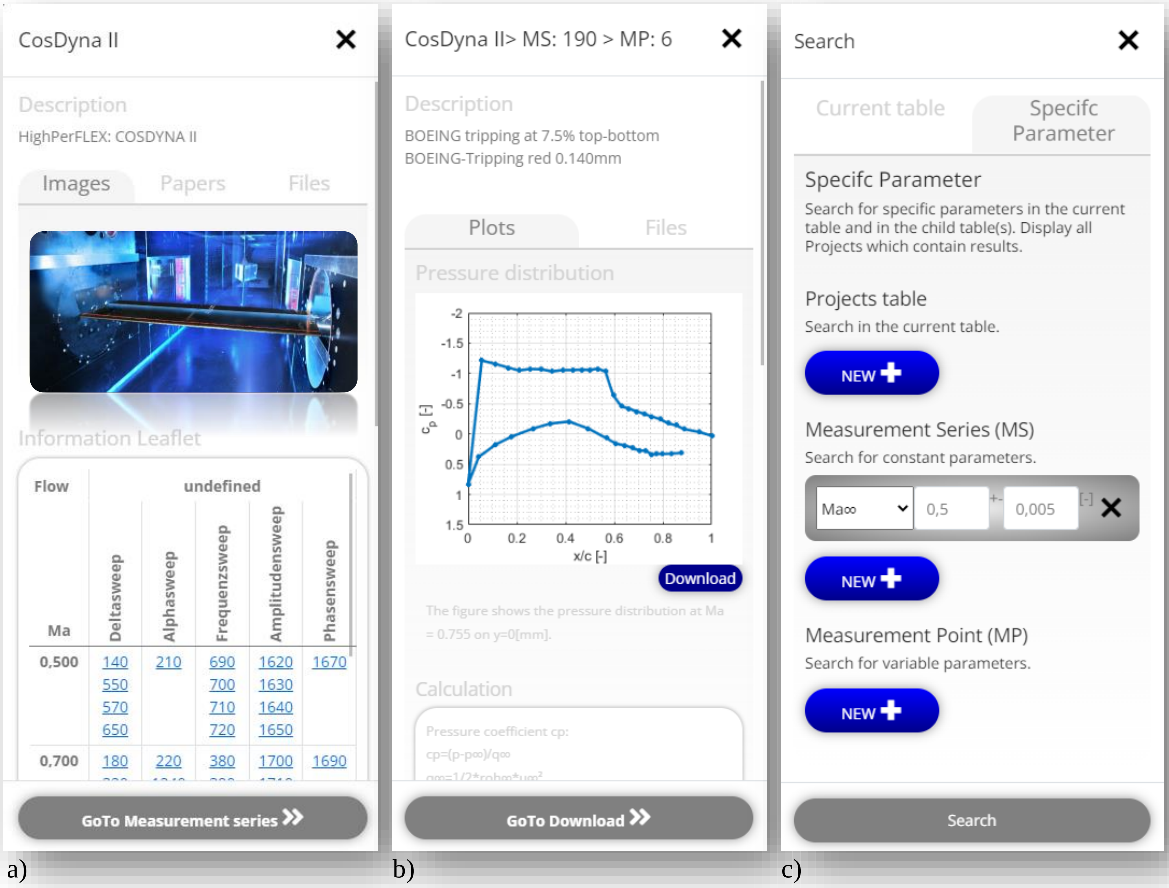


Figure 4: Easy access to project specific files (a); Fast access to measurement data (b); Cross-project search (c)

### *3.1.2 Creating a new Measurement Campaign*

The AeDb database structure also offers the possibility for a test engineer to create a new measurement campaign with just a few clicks. The scientist only has to select what he/she wants to measure, then a measurement protocol and measurement campaign gets automatically created. Furthermore, the newly created measurement campaign can immediately be used to work through, edit and comment on the measurement protocols during the ongoing experiment.

### *3.1.3 Partial-Automatization of Measurement Campaigns*

Additionally, each person involved in the experiment can see and work in the current progress of the campaign, can add important comments and set the own work status. The status of all persons then can be used as multi-person-agreement, what means for example, if person 1 sets a parameter A while person 2 sets a parameter B, the system waits for both persons to complete their tasks. As soon as all test engineers are "Ready", the system gives a "green light" for the measurement. Now the leading test engineer can start the measurement. In the past, measurement points were often accidentally triggered or skipped, with AeDb this is now a thing of the past. Finally, after the measurement is done the data gets synchronized with the database and uploaded. Especially in larger experiments with several participating persons, this is an enormous simplification of work.

### *3.1.4 Status/Process monitoring of Measurement Campaigns*

After the measurement has been done, all measurement data is redundantly uploaded to the database, with that the test engineer or an external scientist can immediately view the measurement data online and check its quality by inspecting e.g. the pressure distribution. This offers the enormous advantage of being able to react quickly to a phenomenon or to compare the measurement data directly with simulations and with that to adapt the ongoing measurement campaign. This principle of the database and the connections between the different clients is illustrated in Figure 5.

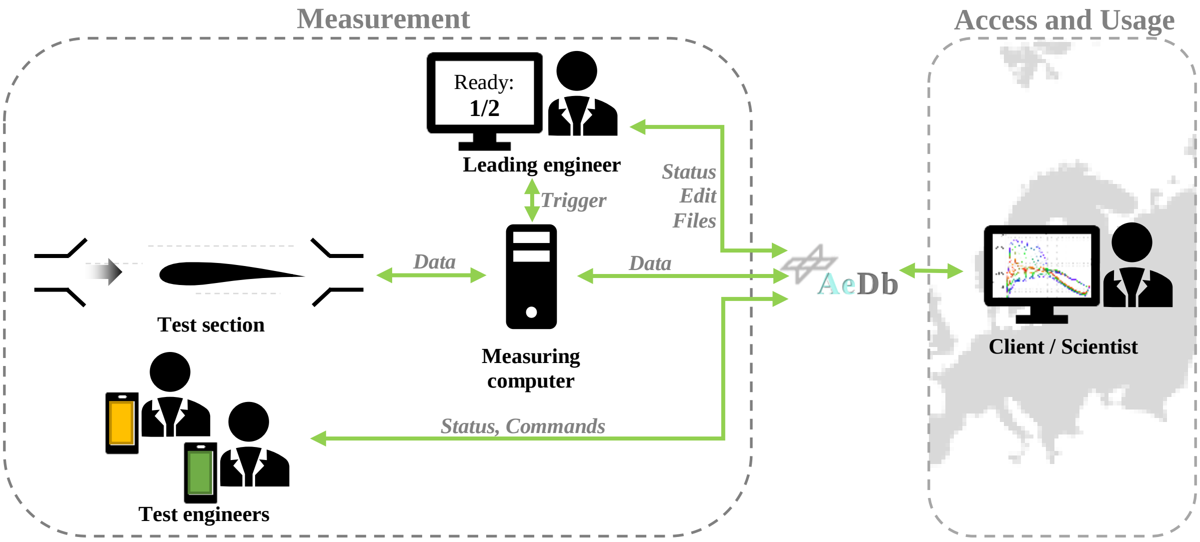


Figure 5: Functional principle of AeDb

### *3.1.5 Security and data access*

In order to protect the use of data, AeDb is secured in several ways. First of all, every user needs an official DLR (guest) account with access authentication to the DLR intranet. Without this an access to AeDb is denied. Furthermore AeDb continuously checks for a valid DLR (guest) account during logins.

If these criteria are met, AeDb will automatically create a new user (if it has not already done so). Now the user can see all projects marked as "public" and their description (Figure 4 a)), but so far, without access to the measurement data, papers, videos, etc. To get access to a project and its files like shown in Figure 4 b), the user first must send a request for the respective project. After the request is confirmed, the user will get access to the data. Finally, if a user has access to a project, all the associated data can be viewed and called directly via MATLAB or Python. For additional security, the data only can be edited and deleted by a project-related manager or admin.

For non-public, customer faring projects, there are additional security requirements. Here, only an explicitly authorized account has access to these projects. While these projects are not listed for confidently reasons and AeDb is used exclusively for the exchange of data and files requested by the customer.

## 3.2 General structure and routes of the website

The tool is developed with Visual Studio 2019, using an ASP.NET Core application with a Model View Controller. ASP.NET Core is a cross-platform, powerful, open-source framework

for building modern, cloud-enabled and Internet-connected apps. [9] In combination with Bootstrap [10], the programming of modern web applications with Responsive Web Design becomes even more interesting. With the existing libraries, it is easy to develop an application in which the design reacts to the conditions of the respective end device and optimizes the display accordingly.
For partial updating of the web application, Ajax (***A**synchronous **J**avaScript **a**nd **XML***) [11] is used for asynchronous data transfer between the browser and the server. This means, for example, that if a database entry is edited, the entire page does not have to be reloaded (which would also result in a new query of the entire database), but only the changed entry is partially updated on the page. Thus, on the one hand the website loads much faster and on the other hand there is less traffic on the server. The server itself is a virtual server (see Figure 6), with RedHat 8.0 [12] used as the operating system. Furthermore, MySQL [13] as database system and phpMyAdmin [14] as database management system, as well as the web application AeDb itself are installed on the server. The software packages installed on the server are shown in Figure 6 as icons on a blue faded background.

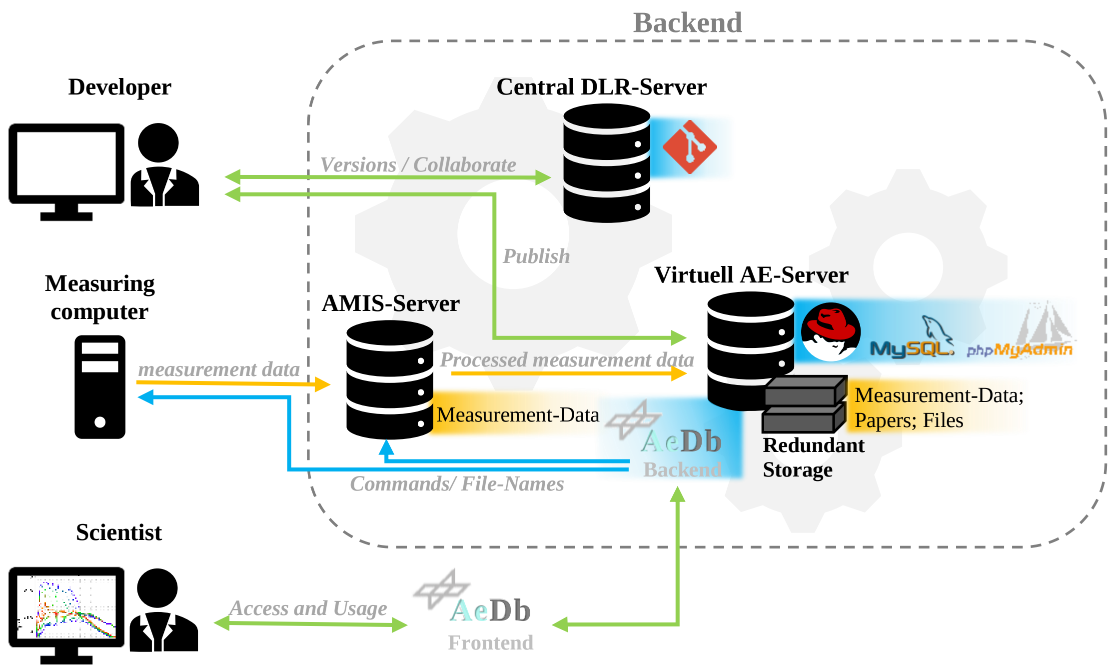


Figure 6: Server dependencies

### *3.2.1 Frontend and Backend - Functional structure of the tool and dependencies*

The virtual AE server described above is also connected to a RAID (***R**edundant **A**rray of **I**ndependent **D**isks*) with several HDDs (***H**ard **D**isk **D**rive*). The processed measurement data and various project-related files such as videos, images and papers are redundantly stored on the hard drives. In addition to the virtual AE server, there is also a central DLR server and the AMIS server. The AMIS server is used to store the "raw" measurement data. During the experiment, the data is automatically uploaded and stored redundantly. On the central DLR server, a Git [15] project of AeDb is stored, which allows developers to access the different versions of AeDb and work collaboratively.
Figure 6 shows the interaction of the different servers with each other and how they are connected in a simplified way. The figure shows a developer who calls up the Git project on the central DLR server in order to work collaboratively on the project. Also shown is his/her direct

connection to the virtual AE server, for example to publish the latest version of AeDb or to manage the MySQL databases.
The next user shown in Figure 6 is a measurement computer. In comparison to Figure 5, the measurement data is uploaded to the AMIS server during a measurement. Here the names and the storage paths of the files are generated via an AeDb extension that can be used offline. In a next step, the "raw" measurement-data can be checked and, if necessary, post-processed and automatically pushed onto the HDDs of the virtual AE server. In the process, AeDb again prescribes the storage path and storage names.
Finally, the actual interaction of the scientist with AeDb is shown. The scientist sees the frontend of AeDb where he/she can view, upload or download various data and papers. The communication between the frontend and backend takes place via the applications described above.

## 4 CONCLUSION AND OUTLOOK

In the past, AMIS was used to collect lots of measurement data. The sharing, searching and evaluation of the data was often very cumbersome and time-consuming. Here the new database application "AeDb" will overhauls many deficits of the old structure. While still in an early stage of development, AeDb already shows its potential through various functionalities.

These functionalities pursue the goal of making the usage of the application as simple and user-friendly as possible. Functionalities that will be implemented by the release include, for example, the ability to search for measurement data and projects with specific parameter combinations (e.g. a specific Mach number for a given angle of attack). Another function is the possibility to link various project related files such as papers, videos, simulations etc. directly to a project and with that to archive the knowledge for future generations. Besides the effect of knowledge storage, AeDb also promotes collaborative work. Therefor also various security algorithms are implemented.
In addition, the creation of new measurement campaigns, will be implemented in the release version.

In the future, further functionalities are planned to simplify the working procedures of an ongoing measurement. For example, all employees will be able to follow the current process of the campaign via AeDb. Thereby they can document important comments and set their own status, so that as soon as everyone finished his/her tasks, the leading test engineer can trigger a new measurement. This will replace many problems that occurred in the past, where e.g. accidentally measurement points were triggered or skipped.

An institute-internal beta release is expected by the end of 2022. A release of the official version for external customers is expected about one year later.

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