

Central Reference Aircraft data System (CeRAS) for research community

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Abstract This paper gives an overview and presents the results of the project CeRAS, which stands for “Central Reference Aircraft data System”. CeRAS is intended to serve as an open platform hosting reference aircraft data and methods that can be used by a research community in aeronautic research projects. The technical topics of the addressed user group lie in the field of overall aircraft design as well as technology integration and evaluation on aircraft level. To enable the communication within the research community the CeRAS homepage has been created (<http://ceras.ilr.rwth-aachen.de/>) and filled with a first short-range reference aircraft dataset. The research community can contribute to and communicate via the CeRAS homepage that is intended to serve as living “open source” platform. The first reference aircraft is called CSR-01 and has been designed with the ILR aircraft design platform MICADO. The aircraft design characteristics are presented and discussed within this paper. Furthermore, common standards for monetary assessment methodologies are presented that have already been established and agreed within the CeRAS research community.

Keywords Central Reference Aircraft data System (CeRAS) · Conceptual aircraft design · MICADO

Abbreviations

ASK	Available seat kilometre
CeRAS	Central Reference Aircraft data System
CPACS	Common Parametric Aircraft Configuration Schema
DOC	Direct operating costs
EI	Emission index
FNG	Flugzeug der nächsten Generation
ICA	Initial cruise altitude
MICADO	Multidisciplinary Integrated Conceptual Aircraft Design and Optimization
MTOW	Maximum take-off weight
NRC	Non-recurring costs
OWE	Operating weight empty
RC	Recurring costs
SAR	Specific air range
SLST	Sea-level static thrust
SPP	Standard passenger payload
TLARs	Top-level aircraft requirements
TSFC	Thrust-specific fuel consumption

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1 Introduction

For most aeronautical research projects, a reference aircraft is required to allow quantitative assessment of the innovation or technology under research in relation to defined reference values. In practice, however, definition and data exchange of common reference aircraft are often inhibited by either restricted data authorisation from industry or

limited availability of consistent reference aircraft data for academia.

Also, reference aircraft data defined or established in one research project are seldom available to another (simultaneous or follow-up) project due to a lack of uniform standards for aircraft design methods and data exchange, which are required to ensure reproducibility and transportability. This can lead to redundant definition processes for the setup of suitable reference aircraft, which is time and cost consuming as well as it complicates the comparison of evaluation results for similar technologies from different projects.

These difficulties have led to the motivation to establish a reference aircraft data system that fulfils the following requirements:

- Complete, consistent and unique description of reference aircraft on overall aircraft level
- Common standards for convenient exchange of reference data and methods within the user group
- Accessibility and extensibility by a larger community of industrial and research partners

Overall objective of the initiation phase of the CeRAS project has been the concept development and creation of the reference aircraft database. A long-term goal could even be the definition and establishment of a notional air transport system that can be used within future German or European research programmes.

The CeRAS concept provides advantages for the users in the addressed research community, both on the academic and the industrial side. Users in research institutes and universities can use the reference aircraft as baseline in research projects and quickly download detailed reference datasets. For users or project coordinators in industry the main intention of CeRAS is a significant reduction of redundant data authorisation processes. Other advantages are a smarter use of external data with improved quality and consistency as well as the possible development of capabilities (e.g. for the creation of internal databases).

Within the CeRAS concept phase, a first reference dataset for a short-range aircraft called CSR-01 (short for CeRAS Short Range—Version 01) has been created. For design and assessment of the CSR-01 the ILR aircraft design software platform MICADO¹ was applied. A detailed description of aircraft design as well as monetary and ecological assessment results of the CSR-01 is given in Sect. 2.

Furthermore, a detailed concept has been worked out for ensuring the requirements stated above, i.e. a consistent description of the reference aircraft and common standards

of data and methods to ensure reproducibility and exchangeability.

Next to technical aircraft design reference data, a standard has been defined for the estimation of direct operating costs (DOC). This standard has already been agreed with the German research community. Another standard for the estimation of recurring costs (RC) is proposed. The description of these monetary assessment standards and its underlying methodologies are described in Sect. 3.

As CeRAS is intended to be used by different partners from industry and research an internet website has been launched on an internal web and file server. Published as freely accessible website, CeRAS is intended to be continuously maintained, developed and extended by different contributors and users from the research community. The creation process, main characteristics and contents of the CeRAS website are discussed in Sect. 4.

2 CSR-01 reference aircraft design

As a first reference aircraft dataset, a short-range aircraft with conventional wing and empennage configuration and two wing-mounted engines has been chosen. The technology standard is of the year 2012 and includes an aluminium wing and fuselage. The aircraft is sized for a design range of 2500 NM and a design payload of 17 t. It is powered by two turbofan engines similar to the IAE V2527-A5 type with a sea-level static thrust (SLST) of 26500 lbf. The reference aircraft has been designed for a set of specified top-level aircraft requirements (TLARs) with the ILR MICADO [28] aircraft design platform. Selected TLARs as well as key aircraft characteristics of the converged MICADO design iteration are summarised in Table 1. The general arrangement is shown in Fig. 1. For a generic notation this first reference aircraft is called CeRAS Short Range 01 (short: CSR-01).

The payload range diagram of the CSR-01 reference design is shown in Fig. 2, where the sizing point at maximum take-off weight (MTOW) is marked by the black square. Design evaluations are conducted at a standard passenger payload (SPP) of 13608 kg. This constitutes a common operating scenario, being equivalent to the standard capacity of 150 PAX in a two-class layout with $90.72 \frac{\text{kg}}{\text{PAX}}$, but no additional cargo payload. Two evaluation missions are defined, one at a range of $R = 500$ NM (cf. blue circle in Fig. 2), and one at the fuel-limited range of $R = 2750$ NM (cf. dark blue square). The study mission at 500 NM is called DOC mission, since it is also used as reference assessment mission for all monetary and ecological assessments. The maximum payload ($PL_{\text{max}} = \text{MZFV} - \text{OWE}$) is determined by maximum passenger and cargo limitations and amounts to 20 t.

¹ Multidisciplinary and Integrated Conceptual Aircraft Design and Optimisation.

Table 1 CSR-01 TLARs and key aircraft characteristics

Parameter	Symb.	Unit	Value
Design range	R	NM	2500
Design passenger capacity		PAX	150
Design payload	PL	t	17.0
Cruise Mach number	Ma_{cr}	–	0.78
Wing loading	W/S	kg/m ²	629.1
Thrust-to-weight ratio	T/W	–	0.312
Maximum take-off weight	MTOW	t	77.0
Maximum landing weight	MLW	t	64.5
Operating weight empty	OWE	t	42.1
Manufacturer’s weight empty	MWE	t	38.2
Maximum zero fuel weight	MZFW	t	62.1
Maximum fuel weight	MFW	t	18.7
Wing area	S_{ref}	m ²	122.4
Wing span	b	m	34.1
Mean aerodynamic chord	MAC	m	4.2
Engine type	–	–	2 × V2527-A5
Sea-level static thrust	SLST	lbf	26500

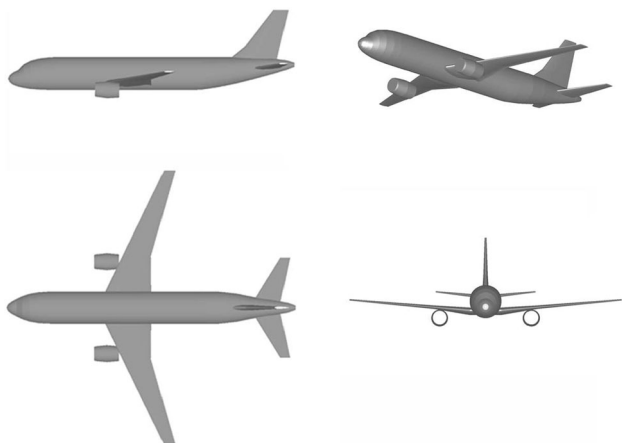


Fig. 1 CSR-01 general arrangement and 3D view

2.1 Engine model and performance characteristics

The CSR-01 propulsion system is designed based on the key specifications given above, i.e. with two engines of a type similar to the IAE V2527-A5 and a thrust class of 26500 lbf per engine.

The MICADO engine performance model (for details cf. reference [28]) is based on a full thermodynamic engine cycle analysis that is simulated using the commercial software GasTurb [18]. To obtain realistic engine

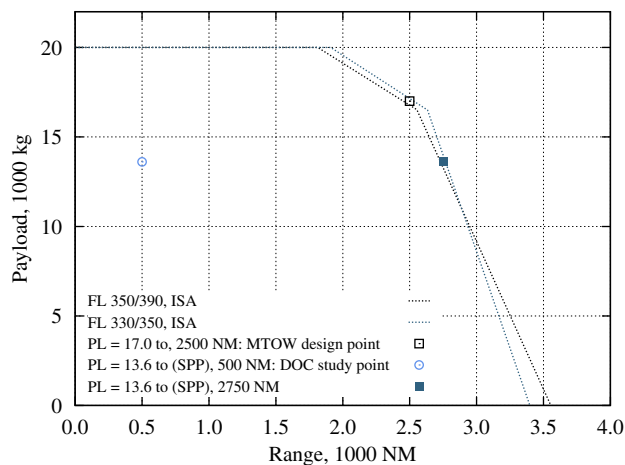


Fig. 2 CSR-01 payload range diagrams

characteristics of the CSR-01 engine, a GasTurb thermodynamics model has been built using public available data for the IAE V2527-A5 engine, cf. for example reference [7]. The thermodynamic model was designed such that the characteristic engine parameters [e.g. thrust or thrust-specific fuel consumption (TSFC)] are close to the available reference data at given conditions. In Fig. 3 bucket curves² of the designed CSR-01 engine model are plotted for the flight conditions at the engine design point ($Ma = 0.78$, 35000 ft); the black and the blue curve represent engine behaviour without and with average cruise offtakes, respectively. Note that the determined (shaft power and bleed-air) offtakes result in an SFC increase of about 5%.

2.2 Wing characteristics

The CSR-01 wing planform with spar positions, and thickness and twist distributions is shown in Fig. 4.

Wing airfoils from the FNG³ aircraft described in reference [6] are used as reference and adapted to the thickness distribution (cf. lower part of Fig. 4). The thickness and twist angle distributions are set based on information from public available sources (e.g. [27]) and in agreement with acceptable lift and load distributions.

The trimmed lift and C_l distribution for the cruise Mach number $Ma = 0.78$ are shown in Fig. 5a. The results are based on the DLR multi-lifting line tool LIFTING_-LINE [12, 13] that is integrated in the MICADO aerodynamic program. The circulation distribution of the CSR-01 wing exhibits a slight under-elliptic behaviour.

² The bucket curve shows the thrust-specific fuel consumption (TSFC) as a function of thrust with varying low-pressure spool speed. The bucket point is reached at the minimum of the curve.

³ Flugzeug der nächsten Generation.

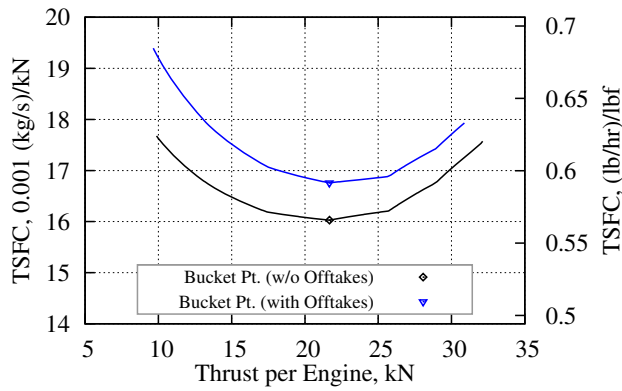


Fig. 3 Engine bucket curves ($Ma = 0.78$, 35000 ft, ISA) without and with average cruise offtakes

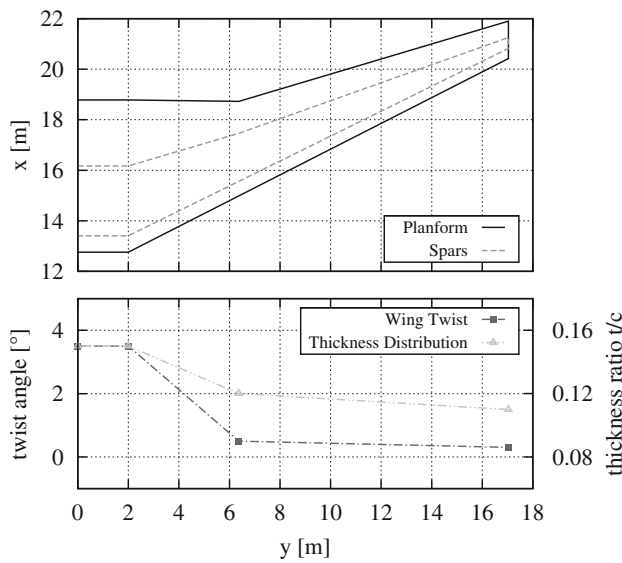
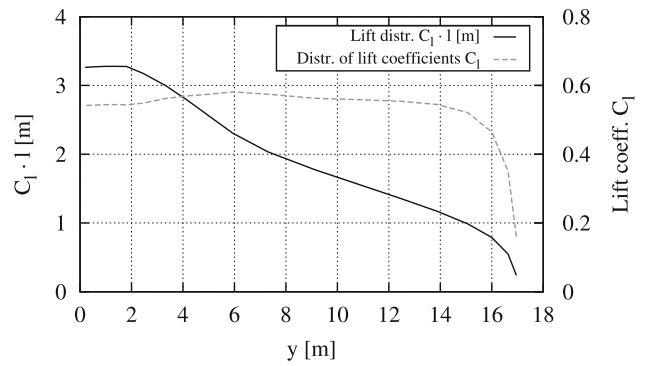


Fig. 4 CSR-01 wing planform, spar positions, thickness and twist distribution

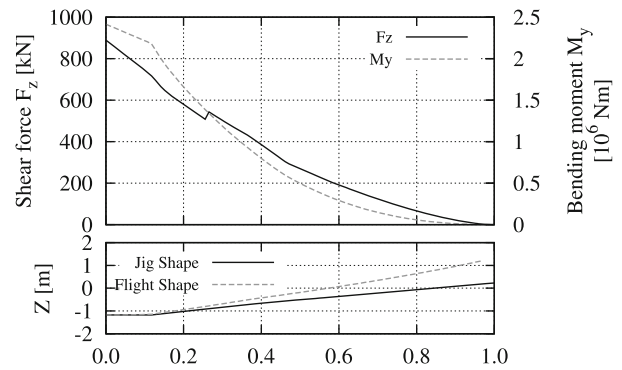
In Fig. 5b the wing shear force and bending moment distribution for the cruise design point is shown determined by the MICADO analytical mass estimation program [31].

2.3 Full aircraft configuration aerodynamics

The MICADO aerodynamic program is used to estimate trimmed full aircraft configuration transonic drag polars; the results are sensitive to the relevant design parameters. A detailed description along with a validation for application to today’s transport aircraft configurations can be found in reference [21]. Total aircraft drag is accumulated from induced drag, viscous drag and wave drag. Mach number dependent polars for different configurations (e.g. take-off, climb, cruise, approach, landing) are exported and used by the MICADO mission simulation program described below.



(a) CSR-01 wing lift and C_l distribution at Ma 0.78.



(b) CSR-01 shear force and bending moment distribution

Fig. 5 CSR-01 wing lift and force distributions

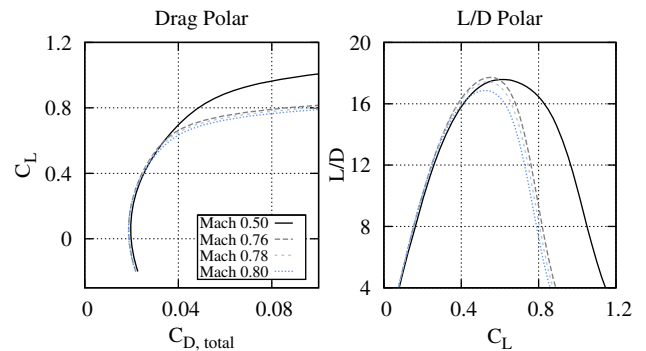


Fig. 6 CSR-01 full aircraft configuration polars (clean, trimmed)

For the converged CSR-01 design, Fig. 6 shows the determined aerodynamic characteristics for the full aircraft clean configuration. The polars are trimmed⁴ for the actual design point. The left figure shows the drag polars for selected Mach numbers and the right figure the L/D curves as a function of lift coefficient (note that in this figure the polars are not cut off at its respective maximum lift

⁴ Polars are trimmed at cruise conditions using an all-movable stabiliser (trim incidence angle $i_{stab,trim} = -0.1^\circ$) such that $C_M = 0$ at $C_{L,cruise}$. No additional trim deflections are used. The pitch up influence of engine thrust on C_M is neglected.

coefficient, which is however considered during mission simulation).

2.4 Mass breakdown

The MICADO mass estimation program comprises semi-empirical and physical analytical models to determine masses and centre of gravity positions for all aircraft and systems components. The implemented models are described in references [4, 19, 31] and are validated against public available data, e.g. reference [25].

Figure 7 illustrates the mass breakdown and shows the components as percentage of the OWE.

2.5 Systems power offtakes

The MICADO systems design program [19, 20, 22] sizes the entire system architecture in terms of masses and mission dependent energy consumption. The implementation of the model is based on a net structure of energy sources, sinks, and conductors. As a consistent and structured definition of the system boundaries, the classification provided by the ATA-100 chapters is applied.

The CSR-01 systems layout is sized for the design mission with a two step cruise flight. The mission is divided into distinct segments to estimate the required bleed-air and shaft power offtakes in dependence on the belonging flight conditions. The mission analysis program described in the next paragraph considers the offtakes (in combination with the underlying engine performance maps) for the calculation of the consumed fuel (cf. Fig. 9).

2.6 Performance

This section presents detailed results determined with the MICADO mission simulation program⁵ as well as other selected performance characteristics of the CSR-01 design. Further, the TLARs are checked for compliance by the underlying physical methods to approve a balanced and realistic design. For the CSR-01 reference design all TLARs could be fulfilled; some of the corresponding performance characteristics are discussed below.

Within the design synthesis, the mission altitude profile is optimised for minimum fuel burn during cruise, which is achieved when flying on the altitude that leads to the highest specific air range (SAR) for a given gross weight. For the optimum selection of cruise altitudes, the altitude changes ΔH are specified (e.g. 1000 ft, 2000 ft, 4000 ft). The altitude profile is then optimised such that SAR is maximised at all cruise mission increments; i.e. if SAR is

lower at the actual altitude H than at the altitude $H + \Delta H$, a step climb is performed. For the climb to the higher flight altitude a constant rate of climb (ROC) of 300 ft/min is used. For the climb decision the additional fuel consumed for the climb segment is considered as well.

For the CSR-01 design the mission simulation is applied for the mission points marked in the payload range diagram in Fig. 2. The simulation results are summarised in Table 2, including (total) mission fuel MF, block fuel BF, and trip fuel TF. Note that for all three missions, the take-off weight equals $TOW = OWE + PL + MF - m_{\text{fuel,taxi,out}}$, where the taxi-out fuel at take-off has been determined to $m_{\text{fuel,taxi,out}} = 276$ kg. For the MTOW sizing mission, it is $TOW = MTOW = 77.0$ t, while for the SPP tank-limited mission, mission fuel MF equals maximum fuel weight (MFW = 18.7 t), and $TOW < MTOW$.

During simulation, cruise steps are optimised as described above with $\Delta H = 2000$ ft. The climb speed schedule is specified as: 250 KCAS/300 KCAS/ Ma 0.76. An alternate distance of 200 NM is assumed for reserve fuel estimation, as well as a contingency fuel of 3% of the calculated trip fuel, according to JAR-OPS 1.255 [1].

The resulting mission profiles for the 2500 NM design mission are shown in Fig. 8. In the upper figure the optimised altitude profile and the profile of the lift coefficient C_L over the mission range are shown. A cruise profile with two steps resulted from altitude optimisation. The sawtooth-like C_L profile is well-arranged around the lift coefficient $C_{L,\text{opt}} = 0.54$, where the maximum L/D is reached (cf. Fig. 6). The thrust curve and the consumed fuel over the design range are shown in the lower part of the figure. Note the thrust peaks in take-off and climb segments showing the realistic consideration of increased fuel consumption on segments with higher thrust ratings.

In Fig. 9 power offtake profiles over the design mission are plotted. For the climb and approach phase a smaller scaling of the range on the x -axis has been used to accentuate the climb speed schedules and the offtake peaks in these phases. The peaks in the shaft-power profile are due to landing gear retraction/deployment as well as retraction and deployment of high lift devices. The reduction of background power during cruise is due to a reduced use of galley power systems [assumed to be mainly used in the climb phase until initial cruise altitude (ICA)]. The bleed-air offtakes are higher during early climb and late descent due to active wing anti-icing; the flight altitude above which wing anti-icing is switched off is set to 12000 ft. The bleed-air offtakes during cruise are mainly used for cabin pressurisation; also, the engine anti-icing system keeps switched on (with a constant offtake of 0.1 kg/s).

⁵ A detailed description of the underlying model is given by Anton [2].

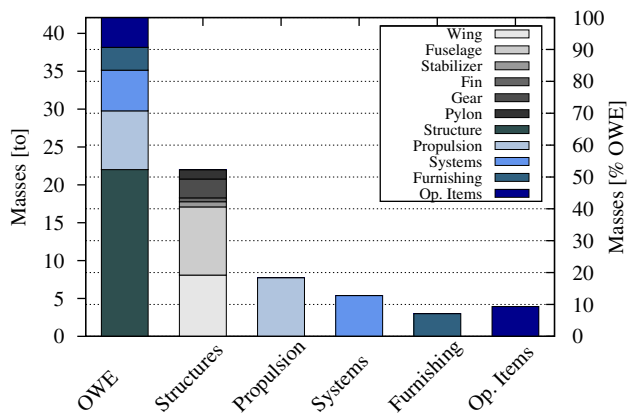


Fig. 7 CSR-01 mass breakdown

Table 2 CSR-01 mission simulation results

Parameter	Unit	MTOW pt.	SPP study	SPP tank-lim.
Mission fuel	kg	18183	6665	18678
Block fuel	kg	14789	3765	15420
Trip fuel	kg	14360	3337	14992
Block time	h	6.01	1.55	6.57

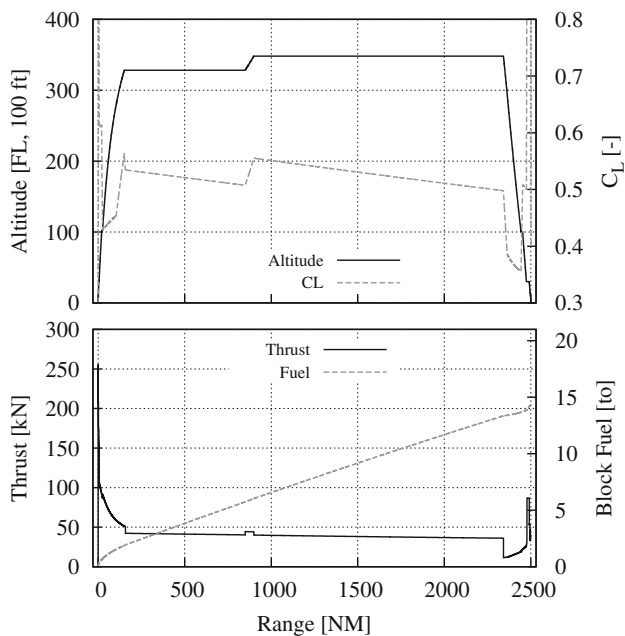


Fig. 8 CSR-01 design mission (2500 NM): altitude and C_L profiles, thrust and fuel curves over mission range

For the SPP 500NM study mission the same mission specifications and reserve fuel estimation assumptions are made, yielding to a block fuel of 3765 kg.

As mentioned, the fulfillment of all TLARs shows the balanced design of the CSR-01 reference aircraft. As an

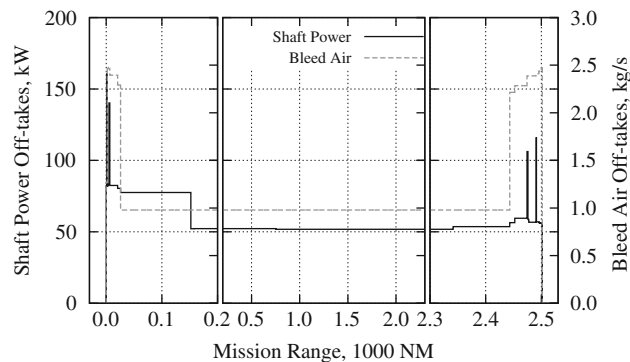


Fig. 9 CSR-01 SPP design mission: power offtakes

example the climb performance results are summarised in Table 3. Note that the time-to-climb is simulated for ISA + 10 atmosphere conditions and with the specified rating *Climb*, which leads to the long time needed due to reduced rate of climbs.

In the lower part of the table, the results for a climb after take-off with MTOW to initial cruise altitude at ISA conditions are summarised in terms of times-to-climb, as well as distance travelled and fuel consumed from brake-release (BR) to ICA. For verification these values have been compared to public available climb Table [1], showing good agreement with deviations lower than 5 %.

The take-off and landing field length characteristics for the CSR-01 aircraft design are not discussed in the scope of this paper but are presented on the CeRAS homepage [14].

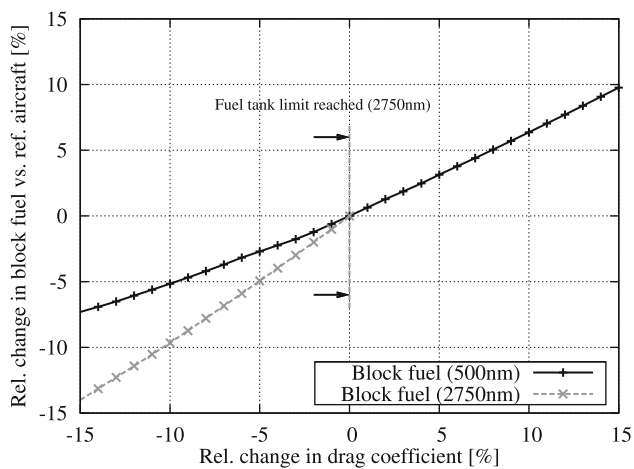
2.7 Design sensitivities

To provide the user group, including those members without design capabilities, the chance to assess new technologies, design sensitivities of the reference design have been determined. Both off-design as well as aircraft resizing sensitivities have been calculated for changes in weight, drag and engine fuel flow. The OWE, C_D and the SFC have been varied in a range from -15 to 15 %. As an example Fig. 10 shows the off-design and resizing results in relative change of block fuel for variations in drag (the sensitivities against variations in mass and specific fuel consumption can be accessed via the CeRAS homepage [14]).

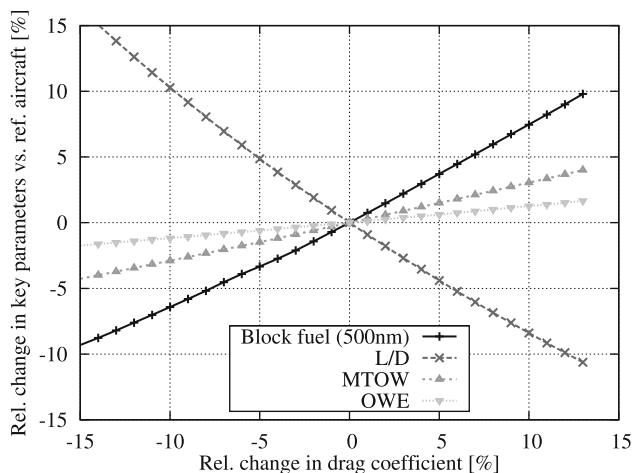
Figure 10a shows the off-design drag sensitivities, where the respective changes have been applied to the converged reference aircraft, and the influence on block fuel on the 500NM SPP study mission has been determined; for comparison the results for the 2750NM SPP mission are shown as well. Since this mission is already tank-limited, off-design points with increased weight, drag or fuel flow led to a violation of fuel weight limit. For the variation in drag the influence on block fuel on the

Table 3 CSR-01 climb performance characteristics

Parameter	Comment	Unit	Value
Calculated performance values for TLARs			
Max. operating altitude	Climb with 100 ft/min, ISA	ft	38815
OEI net ceiling	After T/O @ MTOW, 100 ft/min, ISA	ft	23796
Time-to-climb	From 1500 ft to ICA, after T/O @ MTOW, ISA + 10	min	33.7
Climb to initial cruise altitude (after T/O @ MTOW, ISA)			
Time-to-climb	From 1500 ft to ICA	min	24.2
Time-to-1500 ft	From BR to 1500 ft	min	1.1
Time-to-ICA	From BR to ICA	min	25.3
Range-to-ICA	From BR to ICA	NM	158.5
Fuel-to-ICA	From BR to ICA	kg	1932.8



(a) Without component resizing



(b) With component resizing

Fig. 10 CSR-01 design sensitivities for variation of drag

2750NM mission is nearly 1% for a relative drag change of 1%, as it can be assumed from the Breguet range factor for long distances. For the short 500NM study mission, the large relative amount of climb, acceleration and descent

segments compared to the overall mission reduces the overall impact of drag on block fuel. Also, note that mission-specific boundary conditions are considered such as spoiler deflections in descent segments to keep the specified mission path.

From the parameter variations, results for a 1% deviation have been extracted and summarised for the off-design analysis in Table 4.

For the resizing sensitivity studies, the CSR-01 reference values for wing loading ($W/S = MTOW/S_{ref}$) and thrust-to-weight ratio ($T/W = SLST/MTOW$) are kept constant during MICADO design iteration, since they are the main drivers for fulfilling top-level aircraft requirements. Hence, with varying MTOW, wing (and thus empennage) areas as well as the propulsion system in terms of sea-level static thrust (SLST) are re-scaled. This leads to a combined component resizing and mass snowball effect, e.g. smaller lifting areas and propulsion system become lighter, the reduced OWE leads to less consumed fuel and lower MTOW, which in turn leads to smaller components, and so on. This approach to keep W/S and T/W constant instead of keeping component geometries constant has mainly been chosen because the latter can lead to suboptimal designs, e.g. in terms of an over-powered, too heavy propulsion system. This especially holds for higher deviations from the reference, which lead to significant reduction of MTOW.

Figure 10b shows the resizing results in terms of relative change of the parameters block fuel (on 500NM study mission), MTOW, OWE, and optimum cruise L/D for full aircraft configuration. The L/D results include effects from the changed wing area that scales with MTOW.

2.8 Monetary assessment

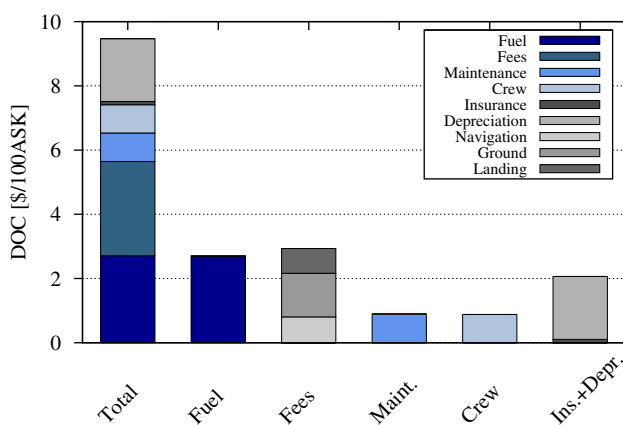
The monetary assessment includes the assessment of direct operating costs (DOC), non-recurring costs (NRC) and recurring costs (RC). For cost estimation semi-empirical cost models are used. For DOC and RC assessment the

Table 4 CSR-01 off-design sensitivities (1% tables)

Parameter	Δ OWE of 1 %	ΔC_D of 1 %	Δ SFC of 1 %
Block fuel @ SPP, 2750 NM	0.70	1.01	1.18
Mission fuel @ SPP, 2750 NM	0.72	0.98	1.16
Block fuel @ SPP, 500 NM	0.42	0.63	1.07
Mission fuel @ SPP, 500 NM	0.56	0.70	1.03

Table 5 CSR-01 operating scenario of study mission

Parameter	Abbr./symbol	Unit	Value
Range	R	NM	500
Payload	PL	kg	13608
Number of PAX	n_{PAX}	–	150
Block fuel	BF	kg	3765.4
Block time	BT	h	1.55
Flight time	FT	h	1.31
Flights per year	FC	–	1913
Fuel price	P_{fuel}	kg	1

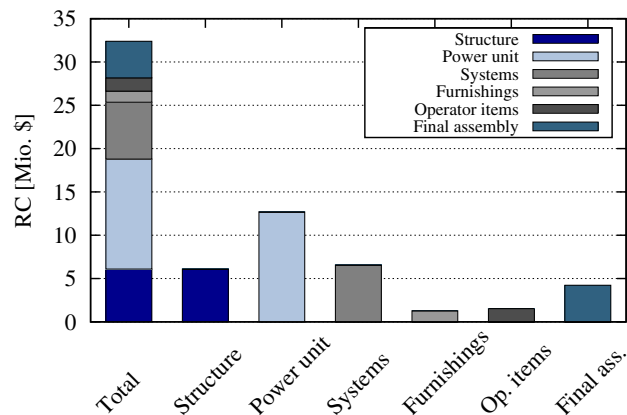
**Fig. 11** CSR-01 direct operating costs breakdown

CeRAS standard methods are taken that have been implemented into the ILR cost programs [9, 23] and are described in Sect. 3. For NRC there has been no standard method defined yet, hence the ILR cost program with its implemented method based on Roskam [29] is used. All monetary values are given for the year 2010.

Table 5 gives an overview of the relevant parameters of the operating scenario of the study mission resulting in direct operating costs of 9.47 USD/(100 ASK) and the cost breakdown as shown in Fig. 11.

Due to the high number of flights per year the fees for ground handling, landing and navigation account for nearly one third of the overall costs.

The recurring costs are 32.39 million USD, assuming a production quantity of 4000 aircraft. The cost breakdown is

**Fig. 12** CSR-01 recurring costs breakdown

shown in Fig. 12, with the power unit costs being the biggest part with nearly 40 %.

Assuming five flight test and two static test airplanes to be build the non-recurring costs are 1481.86 million USD. The biggest cost part are the *Flight test airplanes* with 60.85 % (cf. Fig. 13), that include the costs for manufacturing of flight as well as static test airplanes.

2.9 Ecological assessment

For the ecological assessment the emission species emitted during the study mission are calculated as well as the resulting climate impact that is quantified by different climate metrics.

To calculate the mass of emission species emitted during the different mission phases, flight trajectory and fuel flow data are used, which is provided at each mission point by the MICADO mission analysis program. The emissions that are or can be assumed to be proportional to fuel consumption can be directly calculated from the fuel flow data. This applies to CO₂, H₂O, and SO_x by using the respective emission index⁶ (EI CO₂: 3.149, EI H₂O: 1.2, EI SO_x: 0.00084).

For the other emission species (NO_x, CO, HC, soot) the following calculation methodologies are used:

⁶ The emission index (EI) is defined as the mass ratio of the emission species to fuel.

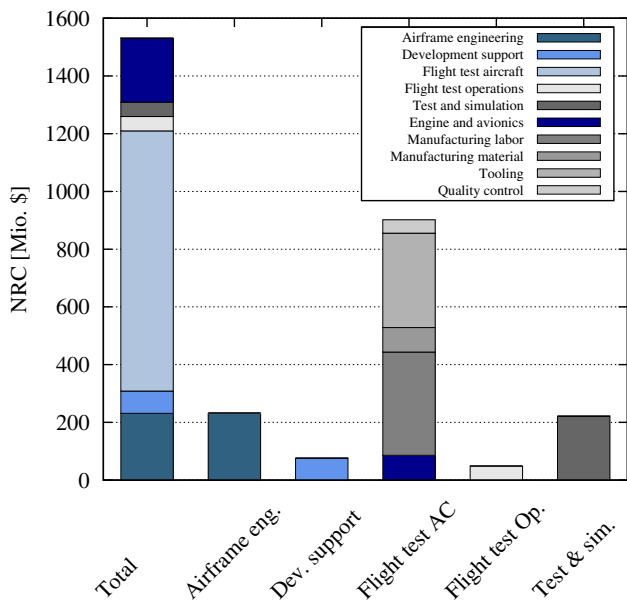


Fig. 13 CSR-01 non-recurring costs breakdown

- NO_x: P3T3 method [26]
- CO: DLR Omega [8]
- HC: DLR Omega [8]
- Soot: DLR correlation (2001) with altitude correction [17].

The emission masses emitted during landing and take-off as well as cruise for the study mission (cf. Table 5) are listed in Table 6.

Climate impact of aviation is highly dependent on the altitude region at which greenhouse gases are emitted, thus emission amounts are not sufficient as indicator for climate change. Dallara [5] has analysed several climate change metrics for the use in aircraft design at different steps of the causal chain of emissions to climate change, and to its impacts and damages. She suggests using the average temperature response as climate change metric that is also used for example by Koch et al. [16] for aircraft design purpose.

The ILR emission tool, described in detail in [10, 30], is based on the climate model of Dallara [5] and calculates for a given time period the following climate impact metrics:

- Radiative forcing (RF)
- Absolute global warming potential (AGWP) after 100 years (AGWP100)
- Global mean temperature change (ΔT)
- Absolute global temperature potential (AGTP) after 100 years (AGTP100)
- Average temperature response (ATR).

In Table 7 the results of the climate impact assessment (of one CSR-01) on the study mission are presented.

Table 6 CSR-01 emissions

Parameter	Landing and take-off		Cruise	
	kg	%	kg	%
CO ₂	2532.87	21.36	9324.24	78.64
H ₂ O	965.208	21.36	3553.22	78.64
SO ₂	0.676	21.36	2.487	78.64
HC	0.040	36.32	0.07	63.68
CO	3.255	53.13	2.871	46.87
NO _x	9.238	34.40	17.617	65.60
PM ₁₀	0.016	30.73	0.035	69.27

Table 7 CSR-01 climate impact

Parameter	Unit	Value
ATR	10 ⁻² mK	0.1
AGTP100	10 ⁻² mK	2.53
AGWP100	10 ⁻⁵ $\frac{W_{yr}}{m^2}$	8.55

Figure 14 shows the time curves of temperature change and AGTP for the assumed time period of 200 years and the aircraft operation period of 25 years.

3 CeRAS monetary assessment standards

To ensure the comparability of aircraft assessment results, common methodical standards are required. The requirements for the CeRAS assessment standards have been defined as follows:

- Based on published methodologies
- Accepted and used by aircraft design community (academia, research, industry)
- Published on CeRAS homepage incl. equations and key data.

Two monetary assessment standards (DOC and RC) have already been proposed to the CeRAS user group. It is planned to define further standards, e.g. for NRC or ecological assessment, in future cooperations and research projects.

For DOC assessment the TU Berlin method [33] has been taken as standard, since it has been already accepted by the aircraft design community as DOC standard. For RC a recommendation has been made, since there was no standard defined yet. All necessary information for DOC and RC calculation like equations, definitions and key data are published on the CeRAS homepage and available for download.

Both methodologies have been implemented into the MICADO cost programs [9, 23] used for aircraft design

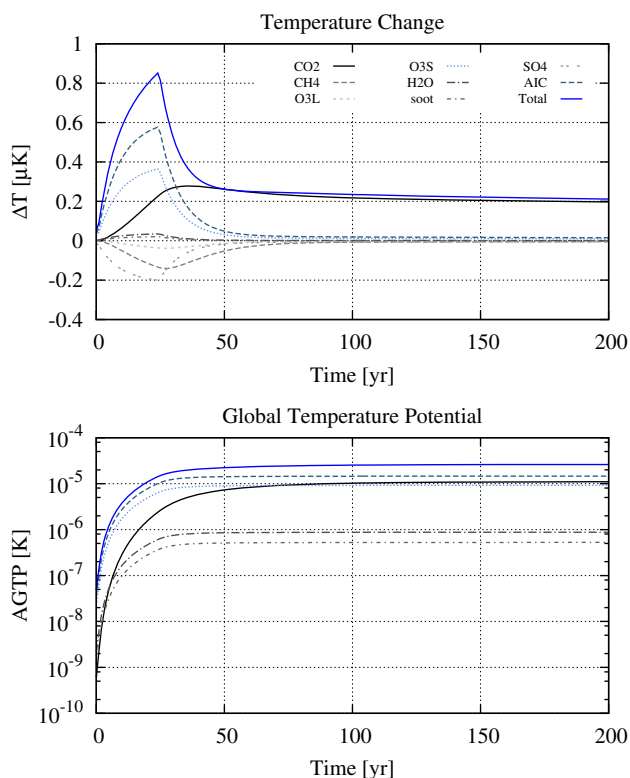


Fig. 14 CSR-01 time curves of temperature change and AGTP

assessment as well as into stand-alone tools that can also be downloaded from the CeRAS homepage. These tools calculate the respective cost breakdown for given aircraft design and operating or manufacturing scenario parameters. The parameters are defined in standardised XML⁷ files that can be downloaded together with the executable program from the homepage.

In the following paragraphs, the CeRAS cost assessment standards are briefly presented.

3.1 Direct operating costs method

The CeRAS DOC standard is based on the TU Berlin DOC method as proposed in lecture notes by Thorbeck [32]. This method has already been presented as DOC standard at the 3rd Symposium on Collaboration in Aircraft Design by Scholz [33]. Some minor modifications have been agreed and implemented into the DOC standard, e.g. the update of the cargo revenue rate from 0.07 to 0.3 €/tkm.

The DOC are broken down into the cost parts shown in Fig. 11: fuel, fees (navigation, landing, ground handling), maintenance (airframe, engine), crew (cockpit crew, flight attendants), and capital (depreciation, insurance).

⁷ As XML (Extensible Markup Language) standard the DLR CPACS format has been chosen (cf. Sect. 4).

The cost model is dependent on aircraft characteristics, operating company dependent parameters as well as different scenarios, e.g. fuel price. For comparability reasons all parameters besides aircraft and mission characteristics are defined as constant in the method, e.g. the ground handling and landing fee rate, the labour rates for maintenance and crew, and the fuel price.

3.2 Recurring costs method

The recommended CeRAS RC standard is based on the NASA RC method by Beltramo et al. [3] and the engine price equation by Langhans [24]. The NASA RC method allows a cost breakdown on detailed aircraft component-level (without engine) and is already used by members of the CeRAS community (e.g. ILR [23] and DLR [24]). The cost equations are functions of the component weight W_i and the production quantity assumed for the aircraft model to be analysed.

The dry engine is treated as purchased part, hence the engine price is needed instead of the engine recurring cost. Therefore a cost equation given by Langhans [24] is used, with which the engine price can be determined as a function of engine dry weight. The price for the dry engine and the costs for the engine system, the latter determined with RC NASA method, add up to the costs of the equipped engine for the aircraft manufacturer.

The RC are broken down into the six cost groups shown in Fig. 12: structure, power unit, systems, furnishings, operator items, and final assembly. These groups are further subdivided, e.g. the structure costs into the costs for wing, fuselage, empennage, landing gear, and pylons.

3.3 Fuel price scenarios

The CeRAS standards are complemented by selected fuel price scenarios to consider the volatility of fuel price that impacts the DOC assessment. Three scenarios were defined—low, mid, high—that include fuel prices for the years 2010, 2020 and 2030 (see Table 8).

The fuel price for 2010 was taken from the DOC standard (cf. Sect. 3.1) for all scenarios. For the mid-price scenario the fuel prices for 2020 and 2030 were taken from the IATA Economic Briefing [15]. Based on the mid-price scenario the low and high price scenarios have been developed. For the low price scenario a linear price rise has

Table 8 Fuel price scenarios in [2010-USD/kg]

Scenario	2010	2020	2030
Low	1	1.14	1.28
Mid	1	1.14	1.62
High	1	1.3	2

been assumed with the same price for 2020 as for the mid-price scenario. The high price scenario has been assumed to have a progressive price development with a stronger price increase than the mid-price scenario.

The recommended fuel price scenarios have still to be agreed by the CeRAS user group. Furthermore, scenarios for other parameters, e.g. emission certificates, should be defined in the future.

4 CeRAS dissemination and public appearance

The created CeRAS homepage is intended to serve as platform, where different partners from industry and research can access the established reference aircraft system and extend it by either more detailed characteristics (e.g. as result from their own calculations or experiments) or by other subparts towards a full reference air traffic system. This required the definition of a common and unique standard that allows all partners to understand and use results from other partners as well as to contribute their own results to the reference system.

The main challenge was to ensure the technical and contextual consistency in the reference data system and a clear exchange of data between different partners for an efficient cooperation.

4.1 Data provision and use of existing standards

For dissemination and data management of the reference system a web and file server has been set up. The server hosts a detailed technical description of the design, which is presented directly in reports, tables and graphics as well as downloadable files and data sheets. The reports and graphics are generated automatically within the aircraft design process with MICADO. To decrease the effort for an update or the creation of new reference data, the MICADO reports (with plots and tables) are matched with the design of the belonging CeRAS web pages, i.e. that MICADO reports and plots can directly be copied or uploaded to the web site.

Existing and already established standards have been preferred if available, to enable convenient use and exchange of data for the majority of the user group. One existing common standard is the DLR CPACS⁸ XML schema [11]. To ensure consistency between different parameterisations, a file converter between the XML standards of MICADO and CPACS has been implemented. The identity of the resulting aircraft models can be exemplified for the outer geometries: a watertight geometry model that is automatically generated (e.g. as a .stp file)

⁸ Common Parametric Aircraft Configuration Schema.

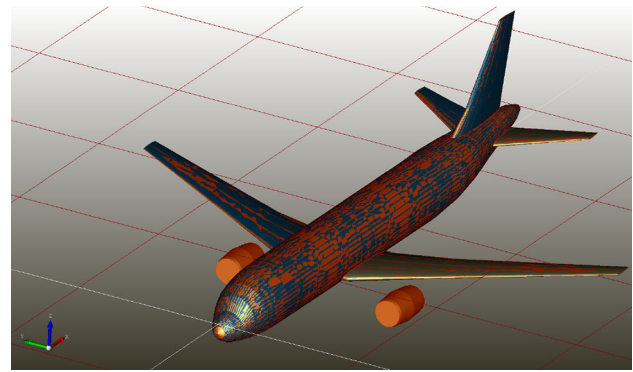


Fig. 15 Comparison of CSR-01 MICADO .stp file (orange) with created CSR-01 CPACS XML file (blue)

from the MICADO XML file is therefore compared to the CPACS file generated with the MICADO-to-CPACS converter. The geometry comparison⁹ for the CSR-01 aircraft is shown in Fig. 15, where the extensively merged colours indicate a geometry match and thus correct conversion of parameters between MICADO and CPACS standards.

4.2 Internal file and web server

An internal server within the ILR/RWTH environment has been set up to be independent of the reliability of external servers. It furthermore ensures secure and individual data handling and configuration of specific homepage areas.

To have the continuing ability for controlling the version of published data, the Subversion control (SVN) system has been installed. Everyone with its own username and password is allowed to checkout or submit data from or to the server. This is one way for getting the latest version of the reference aircraft data and to check differences to older versions.

4.3 CeRAS homepage

The CeRAS homepage itself serves for presenting and exchanging the reference data via the world wide web. The homepage can be reached via the URL <http://ceras.ilr.rwth-aachen.de>.

For the actual database of reference aircraft the open source platform Trac¹⁰ is used. Trac is an environment to manage software development projects, the specific features of which are well suited for the CeRAS database. It provides a wiki for the CeRAS reports, an interface to SVN for version control and further convenient reporting facilities. Trac allows wiki markup in every kind of

⁹ The comparison of a .stp and a CPACS XML file can be done using the DLR TiGL viewer (<http://software.dlr.de/p/tigl>).

¹⁰ <http://trac.edgewall.org/>.

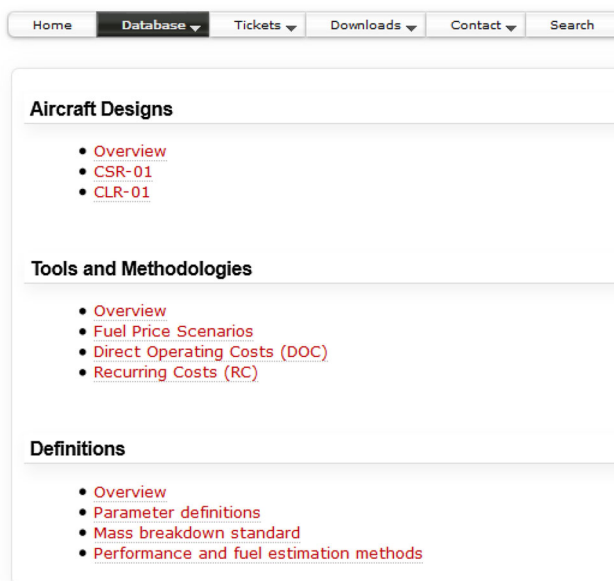


Fig. 16 Overview of CeRAS homepage database contents

message, creating links and seamless references between bugs, tasks, changesets, files and wiki pages. A timeline shows all current and past project events in order, making the acquisition of an overview of the project and tracking progress very easy.

The CeRAS database is structured as follows:

- Home (opening)
- Database (reference aircraft data system)
 - Technical reports with detailed aircraft data
 - Cost methodologies and tools
 - Definitions and descriptions of parameters, standards and methods
- Tickets (communication and reporting)
- Downloads
- Contact

An overview of the content of the database is given in Fig. 16.

The database provides the following technical features:

- Different user roles (*Trac-Admin*, *contributor*, *authenticated*, *anonymous*) and protected areas
- Versioning of designs using Subversion control (SVN)
- Tracking system: the integrated SVN allows to track any kind of changes in reports, files or tickets
- Ticket system: can be used to communicate feature requests, bugs or enhancements
- Download area: contains detailed data sheets, tools and methodologies
- Search function (within wiki pages, tickets, comments and files)

4.4 Process for creation of new reference aircraft

The creation of additional reference aircraft, e.g. the CLR-01 as a long-range aircraft, has to follow a given process:

1. Agreement on a new reference aircraft within the user group
2. Collection of reference data
3. Aircraft design with a sophisticated design environment (according to all TLARs and specifications)
4. Verification within the user group
5. Final design
6. Upload to homepage w.r.t. CeRAS standards, styles, processes, etc.

5 Summary and conclusions

This paper introduced the developed “Central Reference Aircraft data System”, called CeRAS. The CeRAS reference aircraft database is intended to be accessed by a research community focusing on aircraft design and technology evaluation topics. The main results that have been achieved within the CeRAS pilot project are:

- The CeRAS homepage has been created on an internal web and file server to grant public access to different users and enable the communication within the research community (<http://ceras.ilr.rwth-aachen.de/>).
- With the CSR-01 aircraft design, a first reference dataset has been created and uploaded to the CeRAS website. It comprises detailed technical aircraft design and monetary assessment data, provided by user-friendly plots and reports as well as by detailed data files.
- Monetary assessment methodologies for the estimation of direct operating costs (DOC) and recurring costs (RC) have been established. The DOC method has already been agreed by CeRAS user group as common standard.

In a workshop with the German aircraft design community, the CeRAS approach has been approved by all participants as suitable common platform for application in future research projects.

In agreement with the user group the next envisaged steps are the following:

- Agreement on a first CeRAS long-range reference aircraft (CLR-01)
- Meeting or workshop with the German or European research community for the discussion and dissemination of CeRAS
- Use and enhancement of CeRAS in upcoming national and European research projects.

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