



# BADA aircraft performance data for ATC systems

ICAO/Eurocontrol Workshop 2023

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# Overview

- What is BADA?
- Introduction to the BADA 3 model
- BADA licencing

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# What is BADA?

- BADA means Base of Aircraft Data
- BADA is an aircraft performance model, developed and maintained by EUROCONTROL since the early 90's, in cooperation with aircraft manufacturers and operators
- BADA provides data on aircraft performances suitable for trajectory prediction and simulation within ATC tools
- BADA is established as a worldwide standard aircraft performance database for ATM/ATC applications

# BADA users at a glance

1000+ users    50+ countries    200+ organisations

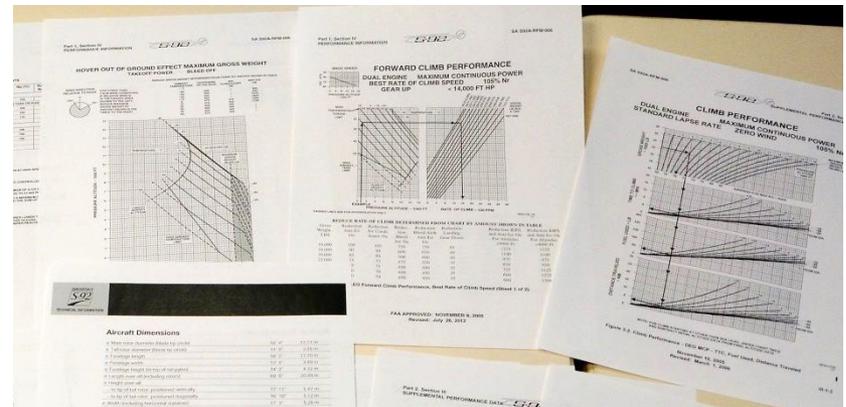


## BADA users

- Many types of organizations: CAA, ANSP, ATM industry, research organizations, universities...
- Many types of applications: ATC operations (FDP, AMAN, flow management), simulations (real- or fast-time), environmental assessments...
- ANSPs all over the world: EUROCONTROL, FAA, ATMB China, NAV CANADA, AirServices Australia, JCAB...
- Examples of users in NAM/CAR Regions:
  - US: FAA, MITRE, MIT, Raytheon, Leidos, Metron...
  - Canada: NAV CANADA, Environment and Climate Change Canada
  - Honduras: COCESNA

# BADA model development

- All BADA aircraft models are developed using reference performance data from the aircraft manufacturer:
  - flight manuals
  - performance engineer tools



- Our main partners:



# BADA model families

- BADA 3:
  - Today's standard model for fixed-wing aircraft
  - Mature, widely used by the ATC/ATM community, covers many aircraft
  - **Recommended BADA family for ATC applications**
  
- BADA 4:
  - New model for fixed-wing aircraft, developed to meet requirements of future ATM systems
  - Still evolving, access is more restricted, covers fewer aircraft type
  
- BADA H:
  - New model for helicopters

# Overview

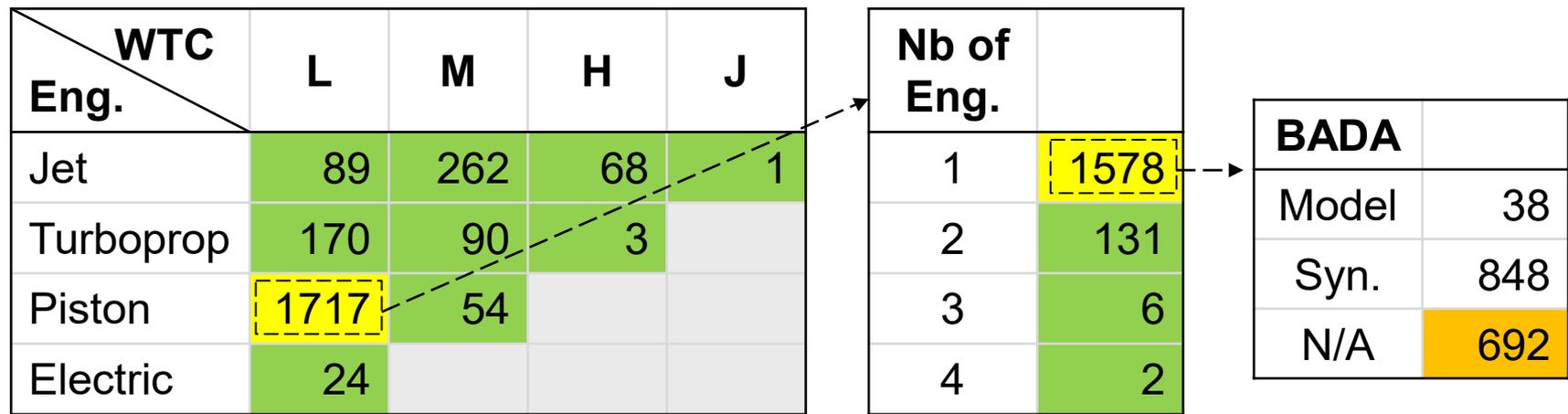
- What is BADA?
- **Introduction to the BADA 3 model**
- BADA licencing

## BADA 3 native models & synonyms

- A given aircraft type can be available in BADA 3 either as a native model, or as a synonym
  
- Native model:
  - Performances are provided as a specific dataset developed for this aircraft type
  - 250+ native models already in BADA 3
  - Wide range of aircraft types: commercial, business, general aviation, military... from many manufacturers
  - *Ex: B77W native model for the Boeing 777-300ER*
  
- Synonym:
  - Performances are considered similar to another type, for which a native model is available
  - 1700+ synonyms already in BADA 3
  - *Ex: B778 (Boeing 777-8) considered as equivalent to B77W*

# BADA 3 coverage of airplane types

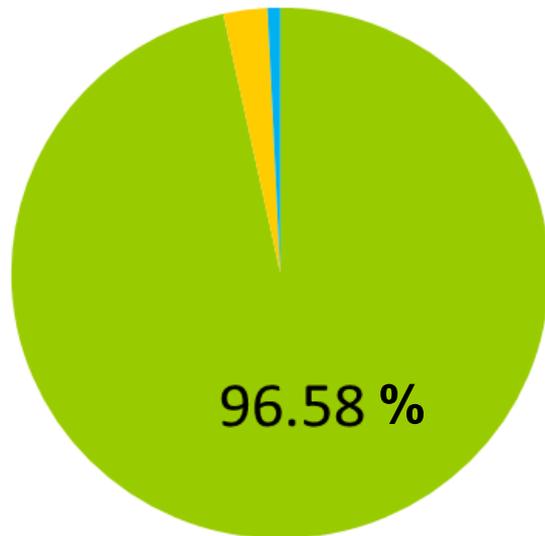
- ICAO Doc 8643 contains **2478** airplane type designators
- BADA 3 covers **1785** types
- Missing types are all Single Engine Piston and will be added over time



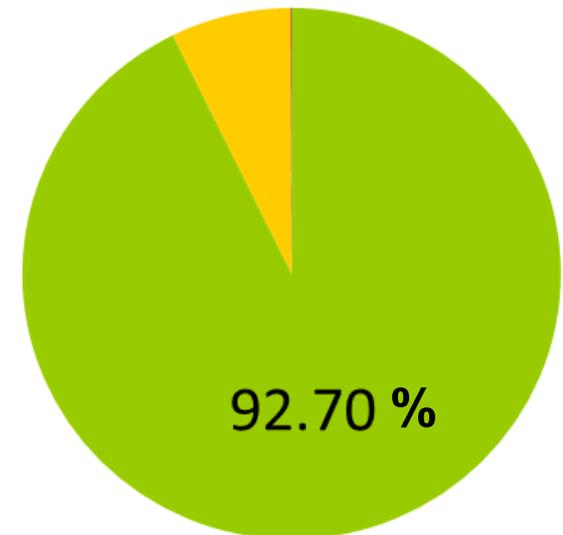
Fully covered by BADA  
 Partially covered by BADA

# BADA 3 coverage of airplane operations

ECAC  
*(IFR operations)*



Worldwide  
*(ADS-B equipped)*



- Models
- Synonyms
- Helicopters
- Non ICAO
- Missing

## BADA 3 update cycle

- Minor update each month to incorporate changes in aircraft type designators (ICAO Doc 8643)
- Major update every 1 or 2 year(s):
  - New aircraft models
  - Improvements to existing aircraft models
- No changes in model specifications since 2010 to avoid costly modifications in ATC systems: only the data are updated
- All the changes are documented for traceability

# BADA 3 content

- Model specifications: description of the formulas, algorithms, file formats, etc. to be implemented in the ATC system
- Dataset:
  - Aircraft type-specific datasets contain, for each native model, all the coefficients and parameters to be used for the performance computations
  - Sample performance tables, computed in nominal conditions, are provided for each native model for verification purposes
  - A synonym file provides a mapping between each aircraft type and its associated native model
- Additional documentation:
  - Accuracy reports provide quality assessment data about the native models and synonym mappings
  - Description of all changes implemented in each new release

# BADA 3: sample aircraft dataset

```

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC A306__.OPF CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC/
CC
CC          AIRCRAFT PERFORMANCE OPERATIONAL FILE
CC
CC      File_name: A306__.OPF
CC
CC      Creation_date: Apr 30 2002
CC
CC      Modification_date: Sep 05 2008
CC
CC===== Actype =====
CD   A306__      2 engines      Jet              H
CC   A300B4-622  with Pw4158 engines              wake
CC
CC===== Mass (t) =====
CC   reference      minimum      maximum      max payload      mass grad
CD   .14000E+03     .87000E+02     .17170E+03     .39000E+02     .15103E+00
CC===== Flight envelope =====
CC   VMO(KCAS)      MMO          Max.Alt      Hmax          temp grad
CD   .33500E+03     .82000E+00     .41000E+05     .32378E+05     -.2716E+02
CC===== Aerodynamics =====
CC wing Area and Buffet coefficients (SIM)
CCndrst surf(m2)   clbo(M=0)      k              CM16
CD 5 .26000E+03    .13150E+01     .84080E+00     .00000E+00
CC Configuration characteristics
CC n Phase Name   vstall(KCAS)   CD0            CD2            unused
CD 1 CR Clean     .15100E+03     .20591E-01     .51977E-01     .00000E+00
CD 2 IC S15F00    .11700E+03     .33057E-01     .45362E-01     .00000E+00
CD 3 TO S15F00    .11700E+03     .33057E-01     .45362E-01     .00000E+00
CD 4 AP S15F15    .10900E+03     .38031E-01     .44932E-01     .00000E+00
CD 5 LD S30F40    .97000E+02     .78935E-01     .44822E-01     .00000E+00
CC Spoiler
CD 1 RET
CD 2 EXT
CC Gear
CD 1 UP
CD 2 DOWN
CC Brakes
CD 1 OFF
CD 2 ON
CC===== Engine Thrust =====
CC      Max climb thrust coefficients (SIM)
CD   .29716E+06     .51306E+05     .56296E-10     .84814E+01     .44597E-02
CC   Desc(low) Desc(high) Desc(level) Desc(app) Desc(ld)
CD   .32012E-01     .40310E-01     .15161E+05     .13124E+00     .39136E+00
CC   Desc CAS Desc Mach unused unused unused
CD   .30000E+03     .78000E+00     .00000E+00     .00000E+00     .00000E+00

```

# BADA 3: sample performance table



BADA PERFORMANCE FILE											Apr 01 2010	
AC/Type: A306__											Source OPF File: Sep 05 2008	
											Source APF file: Mar 05 2009	
Speeds: CAS(LO/HI) Mach Mass Levels [kg] Temperature: ISA												
climb - 250/310 0.79 low - 104400												
cruise - 250/310 0.79 nominal - 140000 Max Alt. [ft]: 41000												
descent - 250/290 0.79 high - 171700												
FL	CRUISE				TAS [kts]	CLIMB			fuel [kg/min]	DESCENT		
	TAS [kts]	fuel [kg/min]				ROCD [fpm]	hi	fuel [kg/min]		TAS [kts]	ROCD [fpm]	fuel [kg/min]
		lo	nom	hi	lo	nom	hi	nom	nom	nom	nom	
0					157	2454	1925	1556	219.7	131	698	84.1
5					158	2437	1907	1536	217.8	132	714	83.3
10					159	2420	1889	1517	215.9	138	730	82.9
15					166	2530	1974	1588	214.9	149	774	82.9
20					167	2512	1955	1568	213.0	181	988	28.3
30	230	53.3	69.9	88.8	190	2940	2289	1852	212.9	230	1287	20.2
40	233	53.4	70.1	89.0	225	3474	2695	2191	214.6	233	1306	19.9
60	272	60.0	73.3	88.5	272	4081	2973	2285	213.7	272	1520	19.3
80	280	60.3	73.8	89.1	280	3932	2846	2168	206.0	280	1561	18.7
100	289	60.5	74.2	89.7	357	3897	2879	2256	208.7	334	1984	18.0
120	297	60.9	74.6	90.3	367	3687	2706	2101	200.8	344	2027	17.4
140	378	82.2	91.8	102.8	378	3472	2527	1941	193.0	354	2071	16.8
160	389	82.4	92.3	103.4	389	3250	2344	1776	185.2	365	2075	16.1
180	401	82.7	92.7	104.0	401	3023	2156	1607	177.4	376	2119	15.5
200	413	82.9	93.1	104.6	413	2790	1962	1434	169.6	387	2163	14.9
220	425	83.2	93.5	105.2	425	2551	1765	1256	161.8	399	2206	14.2
240	438	83.4	93.9	105.8	438	2308	1563	1074	154.1	412	2248	13.6
260	452	83.6	94.3	106.5	452	2059	1357	889	146.3	425	2289	13.0
280	466	83.8	94.7	107.1	466	1807	1147	700	138.6	438	2330	12.3
290	468	82.3	93.6	106.4	468	2417	1499	872	134.2	445	2349	12.0

# BADA 3 implementation in ATC system

- Option 1 (**recommended**):
  - Implement the full physics-based BADA model
  - Allows dynamic computation of performances using all known information about the flight (aircraft weight, speed, temperature...)
  - Option selected by many industry products from Thales, Indra, Barco/Frequentis, Lockheed/Leidos...
  
- Option 2:
  - Use only the pre-computed performance tables from BADA
  - Available performances are limited to predefined conditions (nominal aircraft weight, speed profile...)
  - Should be limited to legacy ATC systems that can only use static performance tables

# BADA 3 implementation: physics-based model

Rate of climb/descent  
acc/dec

$$(\text{Thr} - D) \cdot V_{TAS} = mg_0 \frac{dh}{dt} + mV_{TAS} \frac{dV_{TAS}}{dt}$$

Thrust:  $\text{Thr}_{\max \text{ climb}} = (\text{Thr}_{\max \text{ climb}})_{ISA} \times (1 - C_{Tc,5} \cdot \Delta T_{\text{eff}})$

$$(\text{Thr}_{\max \text{ climb}})_{ISA} = C_{Tc,1} \times \left( 1 - \frac{H_p}{C_{Tc,2}} + C_{Tc,3} \times H_p^2 \right)$$

```
----- Engine Thrust -----
Max climb thrust coefficients (SIM)
.29716E+06 .51306E+05 .56296E-10 .84814E+01 .44597E-02
```

Drag:  $D = \frac{C_D \cdot \rho \cdot V_{TAS}^2 \cdot S}{2}$

$$C_D = C_{D0,CR} + C_{D2,CR} \times (C_L)^2$$

Configuration characteristics					
n	Phase	Name	Vstall(KCAS)	CD0	CD2
1	CR	Clean	.15100E+03	.20591E-01	.51977E-01
2	IC	S15F00	.11700E+03	.33057E-01	.45362E-01
3	TO	S15F00	.11700E+03	.33057E-01	.45362E-01
4	AP	S15F15	.10900E+03	.38031E-01	.44932E-01
5	LD	S30F40	.97000E+02	.78935E-01	.44822E-01

⇒ Performances can be computed at any weight, speed, altitude...

# BADA 3 implementation: pre-computed tables

Only 3 weights

Only 1 speed profile

```

BADA PERFORMANCE FILE
AC/Type: A306___
Source OPF File: Sep 05 2008
Source APF file: Mar 05 2009
Temperature: ISA
Max Alt. [ft]: 41000

Speeds: CAS(Lo/Hi) Mach Mass Levels [kg]
climb - 250/310 0.79 low - 104400
cruise - 250/310 0.79 nominal - 140000
descent - 250/290 0.79 high - 171700
    
```

FL	CRUISE				CLIMB			DESCENT				
	TAS [kts]	fuel [kg/min]		TAS [kts]	ROCD [fpm]	fuel [kg/min]	TAS [kts]	ROCD [fpm]	fuel [kg/min]			
		lo	hi	lo	nom	hi		nom	nom			
0				157	2454	1925	1556	219.7	131	698	84.1	
5				158	2437	1907	1536	217.8	132	714	83.3	
10				159	2420	1889	1517	215.9	138	730	82.9	
15				166	2530	1974	1588	214.9	149	774	82.9	
20				167	2512	1955	1568	213.0	181	988	28.3	
30	230	53.3	69.9	88.8	190	2940	2289	1852	212.9	230	1287	20.2
40	233	53.4	70.1	89.0	225	3474	2695	2191	214.6	233	1306	19.9
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160	389	82.4	92.3	103.4	389	3250	2344	1776	185.2	365	2075	16.1
180	401	82.7	92.7	104.0	401	3023	2156	1607	177.4	376	2119	15.5

➡ Performances available only for pre-defined weight, speed, altitude...

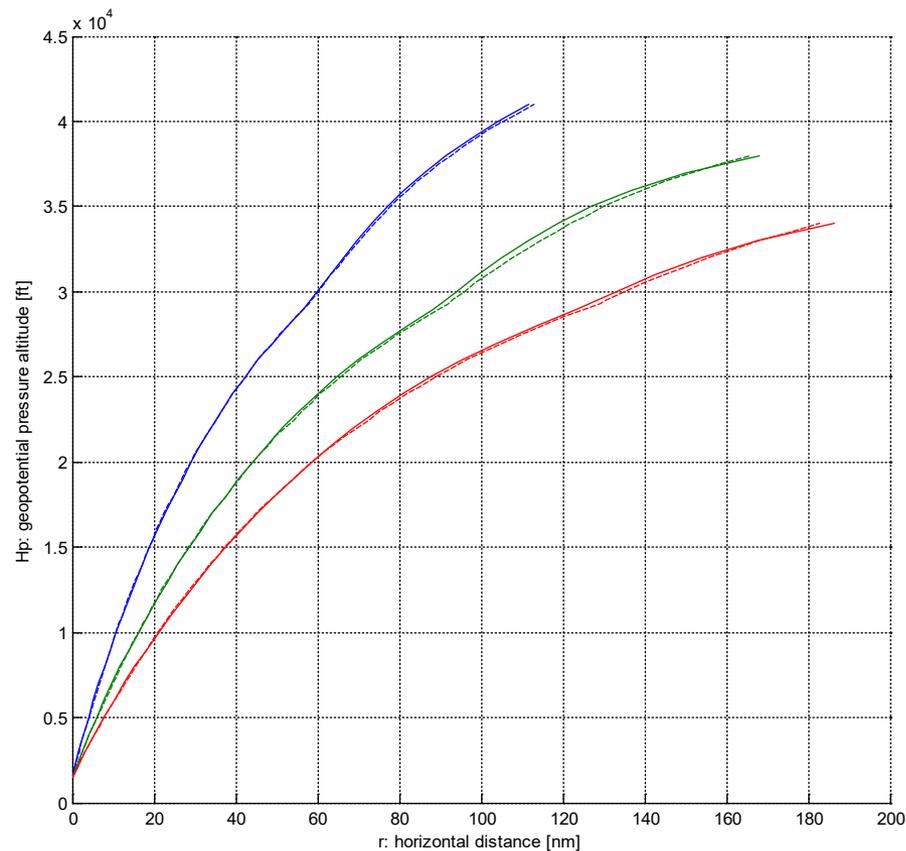
## BADA 3 performance data

- Main performance data provided by BADA:
  - Thrust and drag => computation of rate of climb/descent, acceleration
  - Fuel flow
  - Flight envelope (in terms of speed, altitude, weight...)
  - Nominal speed profiles (take-off, climb, cruise, descent, landing)
- BADA provides the 'instantaneous' performances (e.g. ROCD, airspeed), not a 4D trajectory: the ATC system is in charge of computing the final trajectory (incl. constraints, weather, etc.)

## BADA 3 accuracy overview

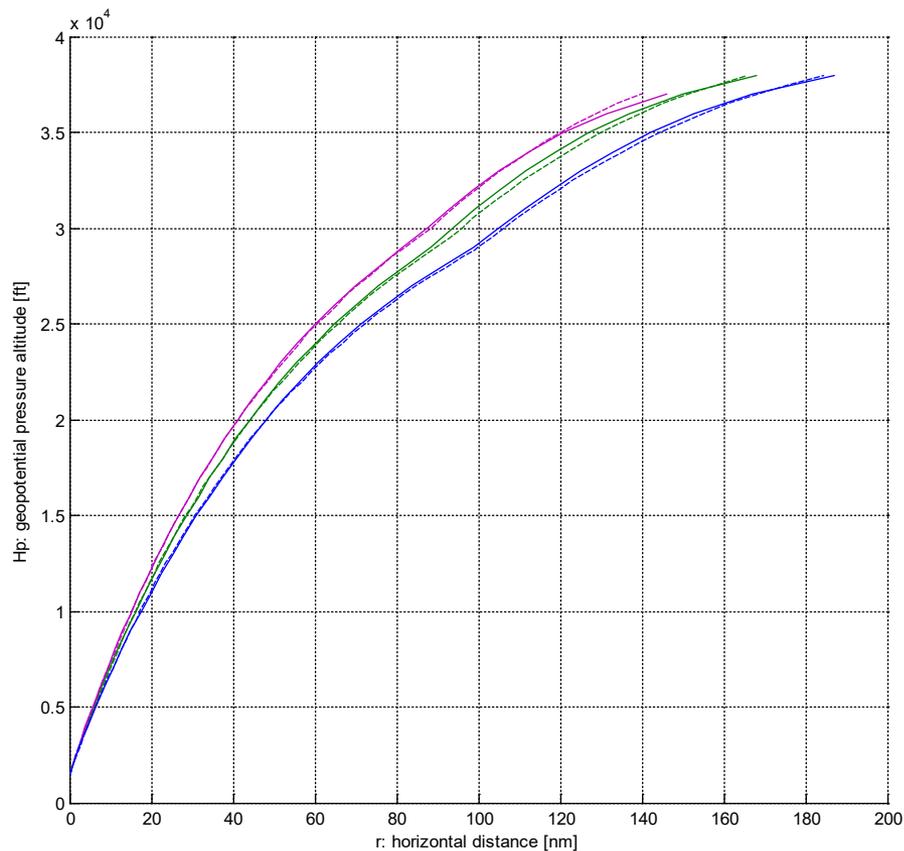
- BADA 3 meets very well the accuracy requirements of many ATC/ATM applications
- Error/uncertainty is typically much higher in the input conditions (e.g. aircraft weight) than in the BADA model itself
- Following plots illustrate typical accuracy:
  - In the vertical profile: most important to ATC
  - When aircraft weight and speed are known
  - Reference data (full lines) vs BADA 3 (dashed lines)

# BADA 3: Typical jet climb profile (1)



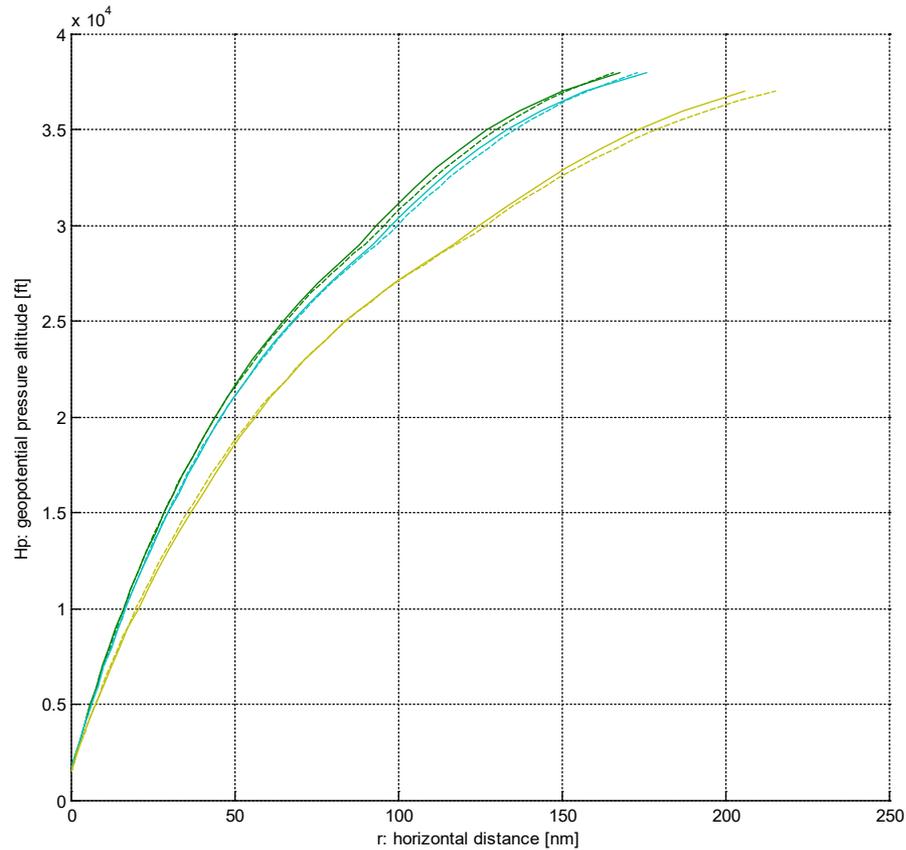
Various weights from 150 to 255 tons

# BADA 3: Typical jet climb profile (2)



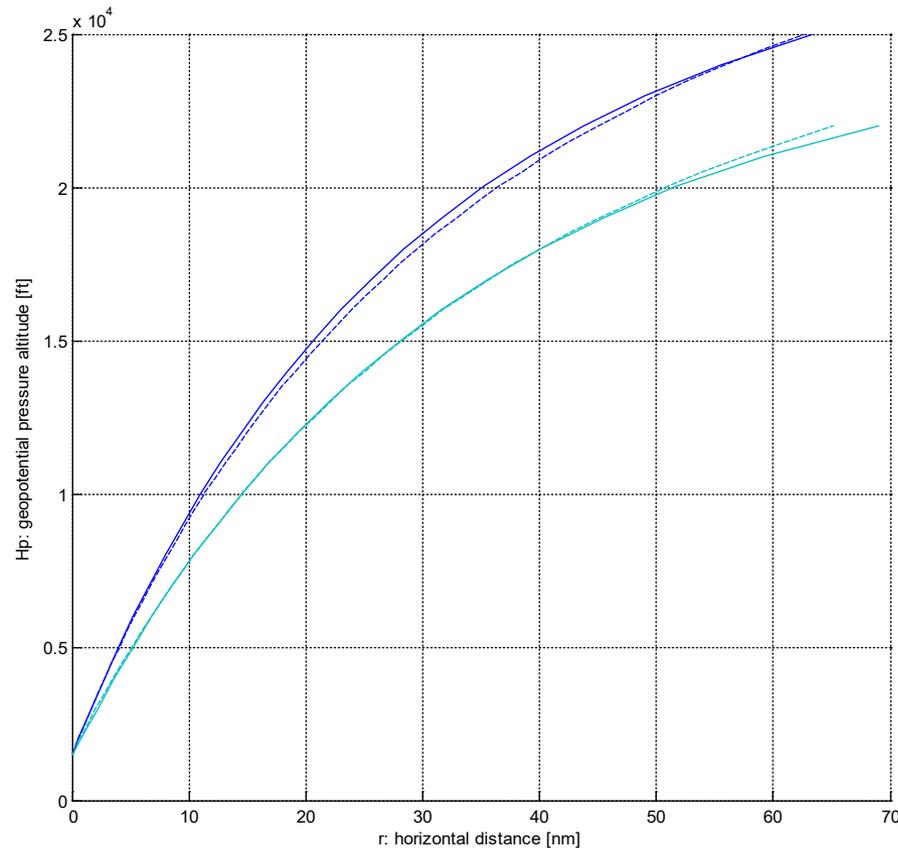
Various speeds from 280/0.74 to 320/0.82

# BADA 3: Typical jet climb profile (3)



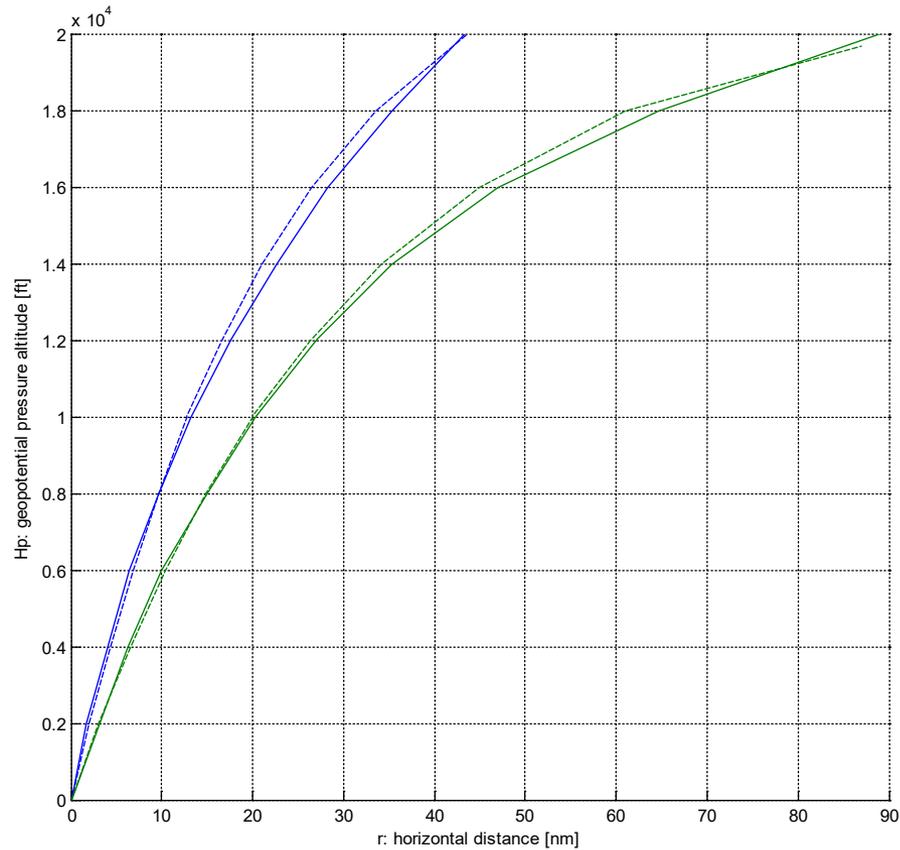
Various temperatures from ISA to ISA+20

# BADA 3: Typical turboprop climb profile



Various speeds from 170 to 190 KCAS

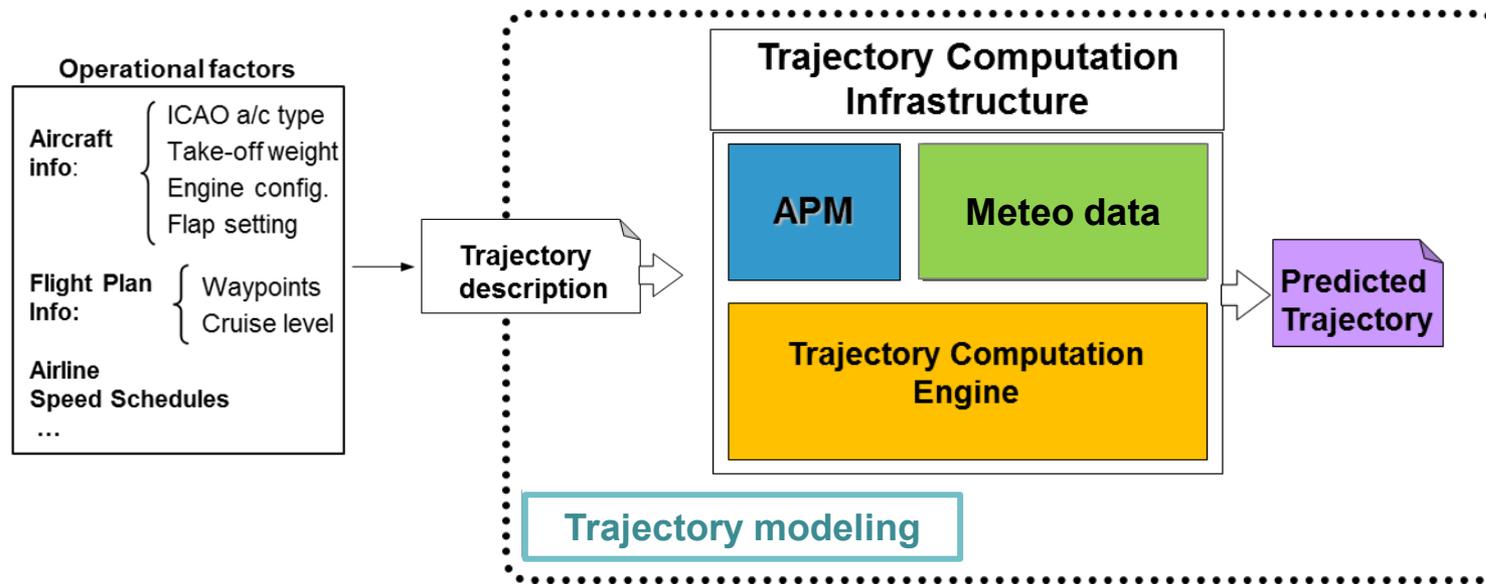
# BADA 3: Typical piston climb profile



Various weights from 1.2 to 1.6 tons

# Trajectory prediction accuracy

- BADA is only one component of the Trajectory Prediction system:

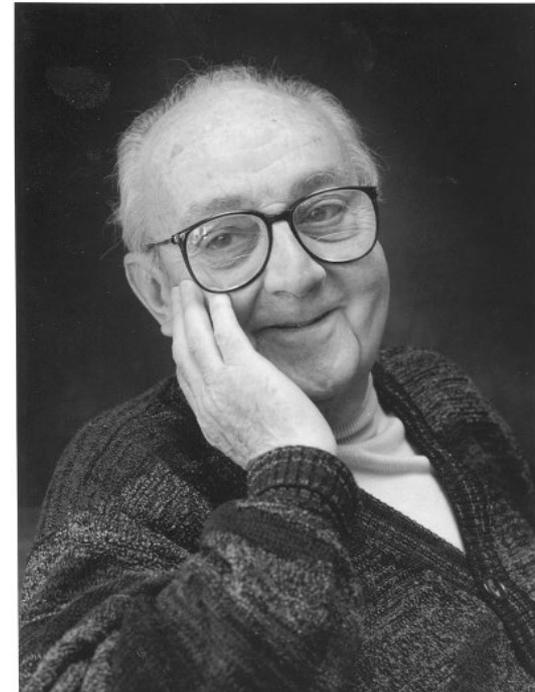


- The accuracy of the predicted trajectory also depends on:
  - The design/algorithms of the trajectory computation tool
  - The quality of the inputs (meteo, aircraft weight...)

# The BADA Team Proverb

**“Remember that all models are wrong,  
but some of them are useful.”**

*George E. P. Box  
Mathematician*



# Overview

- What is BADA?
- Introduction to the BADA 3 model
- **BADA licencing**

## BADA licencing

- The use of BADA is governed by a licence agreement.
- The use of BADA is free of charge.
- EUROCONTROL acts as interface with aircraft manufacturers by obtaining aircraft performance reference data, translating it into BADA and providing it to the international ATM community.
- Appropriate data exchange agreements are in place with the World's major aircraft manufacturers.
- Licence to access BADA is granted after careful evaluation of each request and only for permitted intended use.

# BADA licencing

- **Permitted use of BADA**
  - Modelling and strategic planning of traffic flows in operational ground based **ATM applications (non-safety-critical)**:
    - Flight Data Processing Systems
    - Strategic management of traffic flows
    - Air Traffic Controllers Decision support tools
    - Arrival/ Departure management tools
  - **ATM R&D** modelling and simulation tools
    - evaluation and validation of new operational concepts
    - air traffic flow management
    - flight efficiency studies, cost benefit analysis and similar
    - controller decision support tools

# BADA licencing

- **Permitted use of BADA**
  - **Environmental assessments**
    - solely for the fleet-wide assessment at an airport, regional, or global level
  - **Education and training**
    - Air Traffic Controller's training, aeronautical engineers, etc.

# BADA licencing

## ■ Forbidden use of BADA

- All safety-critical ATM applications and systems
- Any comparisons of any kind between aircraft types (from the same or different aircraft manufacturers) where the intent of such a comparison is to identify a direct relationship between aircraft performances.  
However, general (system-wide) comparisons of aircraft performance of different aircraft types for research purposes to assess ATM system performances may be allowed

## BADA licencing

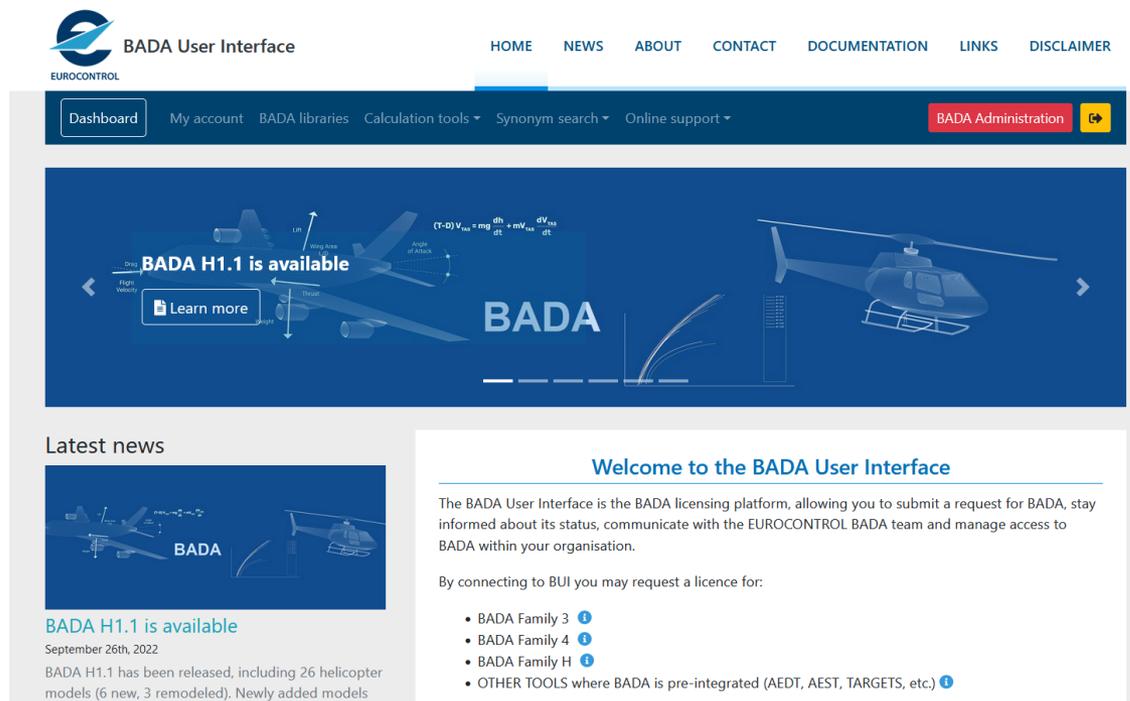
- A dedicated web licencing process and an online user interface have been put in place to facilitate provision of BADA to the ATM community worldwide.
- All necessary information, instructions and relevant links are provided at the BADA web page:

<https://www.eurocontrol.int/model/bada>

- Amongst others, you may find there:
  - A user guide with details on how to make a request for BADA.
  - A copy of the standard licence agreement terms and conditions applicable to all requestors.

# BADA licencing

- The licence grants the licensee the right to:
  - use the BADA Model Specifications and Aircraft Data files
  - access the **BADA User Interface**



The screenshot shows the BADA User Interface website. At the top left is the EUROCONTROL logo and the text "BADA User Interface". A navigation menu includes links for HOME, NEWS, ABOUT, CONTACT, DOCUMENTATION, LINKS, and DISCLAIMER. Below the navigation is a dark blue header with buttons for "Dashboard", "My account", "BADA libraries", "Calculation tools", "Synonym search", "Online support", and "BADA Administration".

The main banner features a blue background with a white aircraft diagram showing lift, drag, weight, and thrust forces. The text "BADA H1.1 is available" is prominently displayed, along with a "Learn more" button. The word "BADA" is written in large white letters. To the right, a helicopter is shown in flight. A mathematical equation is visible:  $(T-D) V_{\text{ref}} = mg \frac{dh}{dt} + mV_{\text{ref}} \frac{dV_{\text{ref}}}{dt}$ .

Below the banner is a "Latest news" section with a sub-header "BADA H1.1 is available" dated September 26th, 2022. The text states: "BADA H1.1 has been released, including 26 helicopter models (6 new, 3 remodeled). Newly added models".

To the right of the news section is a "Welcome to the BADA User Interface" section. It contains the following text: "The BADA User Interface is the BADA licensing platform, allowing you to submit a request for BADA, stay informed about its status, communicate with the EUROCONTROL BADA team and manage access to BADA within your organisation." Below this, it says "By connecting to BUI you may request a licence for:" followed by a list:
 

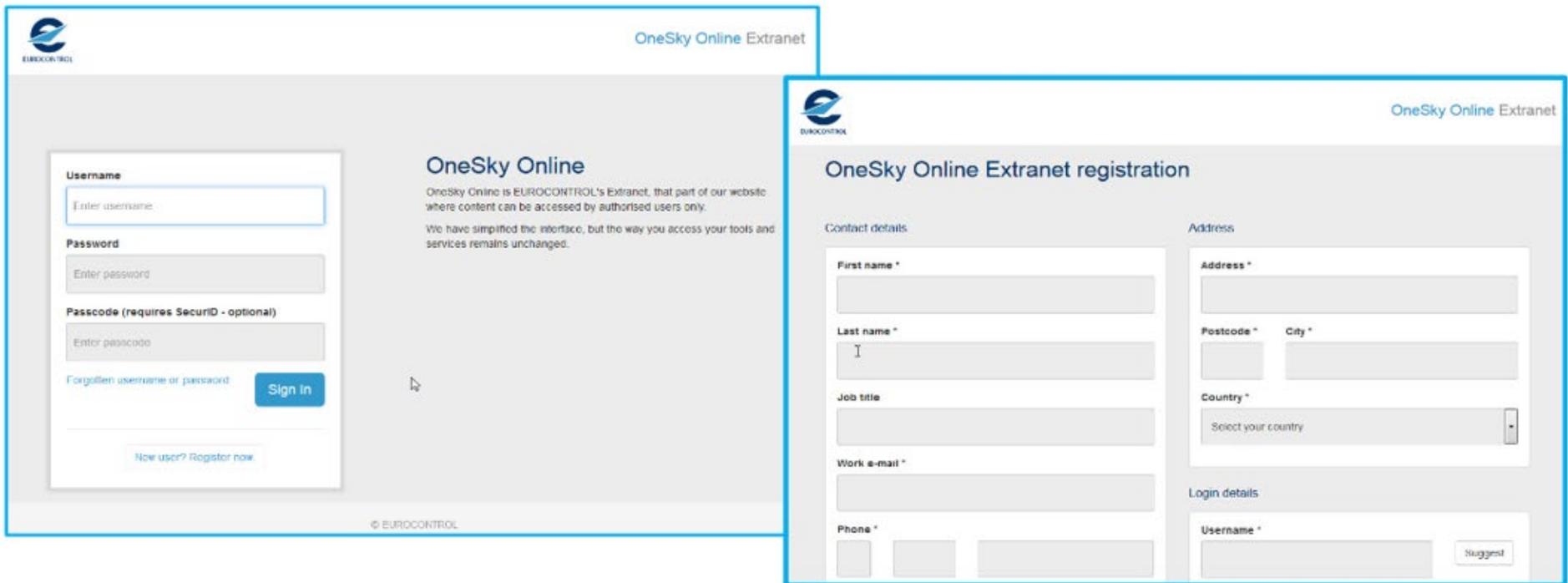
- BADA Family 3
- BADA Family 4
- BADA Family H
- OTHER TOOLS where BADA is pre-integrated (AEDT, AEST, TARGETS, etc.)

# BADA User Interface

- Data Libraries (repository of BADA-related documentation and datasets)
- BADA Calculation Tool for BADA 3
  - a user-friendly interface allowing you to run calculations for climb, cruise and descent profiles for input conditions of your choice
  - speed conversions (TAS/CAS/Mach) at different pressure altitudes
  - transition altitude calculation between any CAS and Mach
  - atmospheric properties according to International Standard Atmosphere (ISA)
- Synonym search tool:
  - identify which BADA aircraft model provides the closest fit to an aircraft type for pre-defined set of criteria
- User Support Application
  - allows to report and track problems, request a change and ask questions related to BADA model implementation and its application

# How to request a BADA licence?

- Step 1: Create a OneSky Online account



The image displays two screenshots of the OneSky Online Extranet interface. The left screenshot shows the login page with fields for Username, Password, and Passcode, and a 'Sign In' button. The right screenshot shows the registration page with fields for Contact details (First name, Last name, Job title, Work e-mail, Phone) and Address (Address, Postcode, City, Country), and a 'Suggest' button.

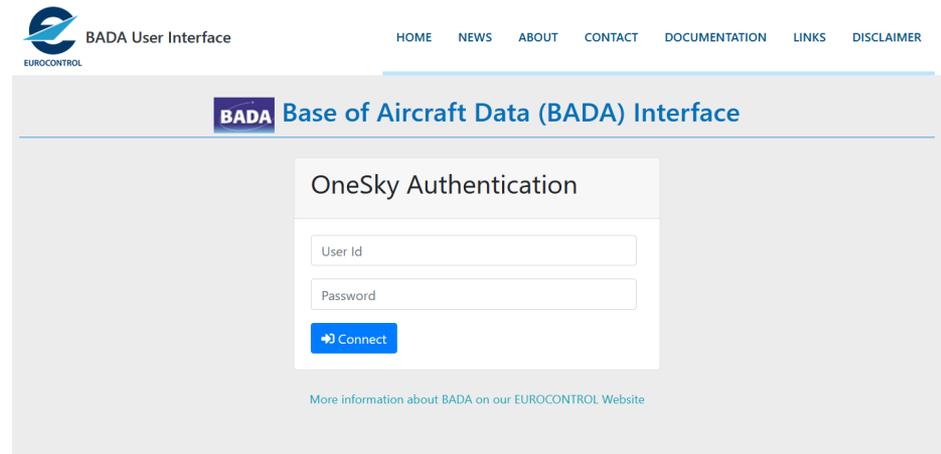
***Please be aware that it may take up to 24 hrs before you can see the link to connect to the BADA User Interface page***

# How to request a BADA licence?

- WHO should make a request on behalf of the organisation?
  - A staff member who will be directly responsible for use of BADA
  - This person is referred to as the BADA Focal Point and he/she will have access to the BADA data and responsibility to obey the terms and conditions of the licence with respect to the use of BADA
  - Considering that a licence agreement needs to be signed by a person who has the legal authority to do so, this also applies to the web-licensing process. The person submitting a request will have to confirm that he/she has the legal authority to “sign” (tick the “approve” or “I agree” box).
  - If the person does not have the legal authority, the legal authority may be delegated by filling an attestation to prove that the application is duly supported by the hierarchy of the organisation.
  
- NOTE that the BADA licence is issued for the specific intended use/ purpose
  - it is not possible to obtain an organisation-wide BADA licence
  
- For any questions, contact: [eih.bada@eurocontrol.int](mailto:eih.bada@eurocontrol.int)

# How to request a BADA licence?

- Step 2: Connect to the BADA User Interface
- Step 3: Submit a request
- Step 4: Follow the progress of your request
- Step 5: Communicate with the BADA review members regarding your request
- Step 6: Accept the licence terms and conditions
- Step 7: Obtain access to the web tools



## Request a licence Your request concerns **BADA 3.15**

1. LICENCE TYPE

2. DETAILS

3. AUTHORITY

4. CONTEXT

Select a type of licence \*

BADA Family 3

Select a version

3.15

# Questions & Answers

