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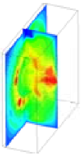

CNR Research Area Bari,
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CIRA IMP-EP project:

Development and Validation of a 1D Model for Hollow Cathode Analysis and Design

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Outline

- *Background*
- *CIRA IMP-EP program: overview*
- *CIRHET-250 Experimental Hall Thruster*
- *Orifice Hollow Cathode (OHC) - Preliminary Design Tool*
    - *Description*
    - *Validation*
- *Conclusions*
- *Future Development*

Background

CIRA, the **Italian Aerospace Research Center**, has been established to create technology know-how in order to support the Italian Aerospace Companies and contribute to the European aerospace development activities in cooperation with

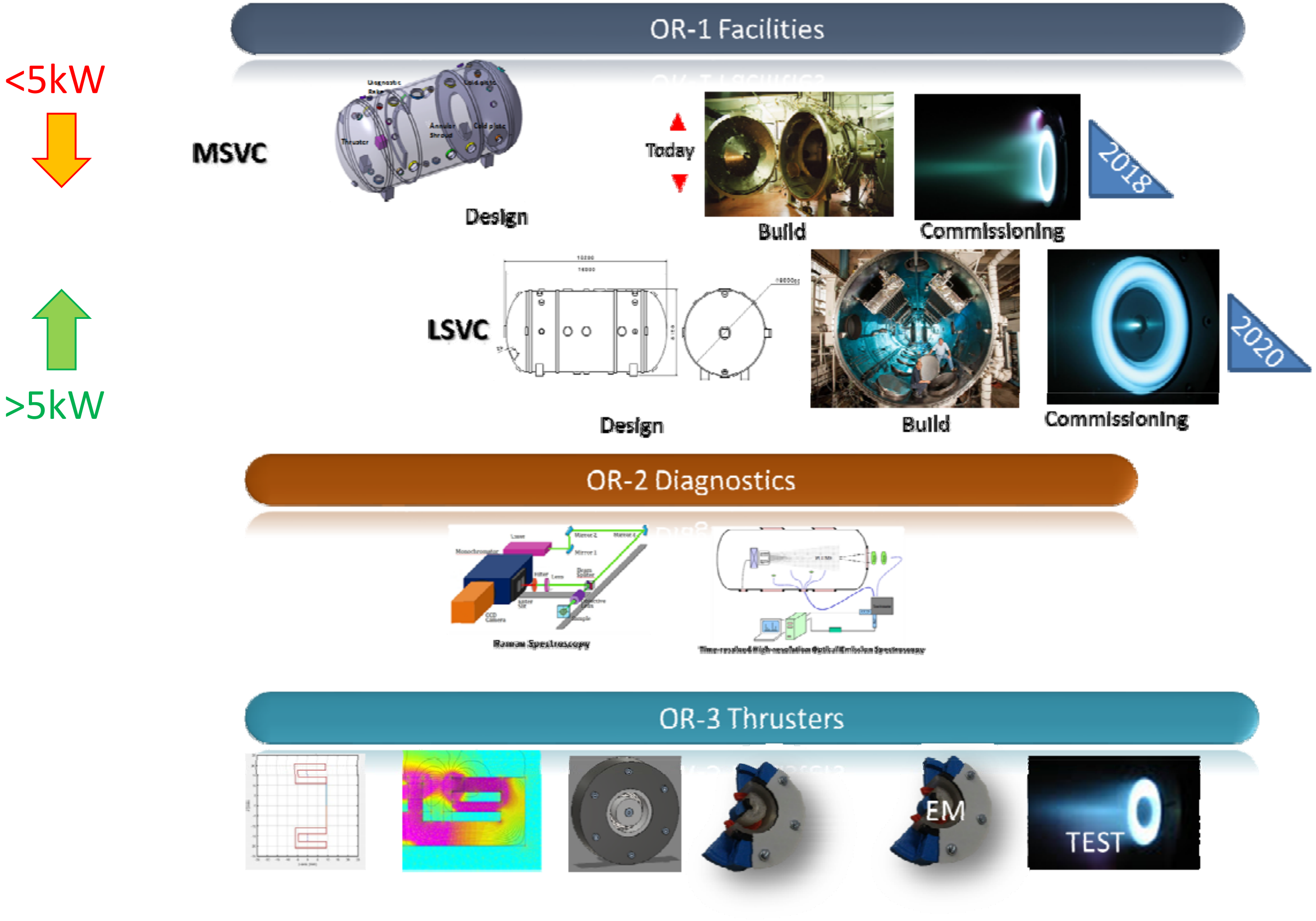
- National and International Institutions
- Universities
- Research Centers
- Companies

One of the main missions is to develop **strategic competences** and **know-how** in the field of **aerospace propulsion**.

At this moment, CIRA is involved in several national and international projects concerning **solid, liquid and electric propulsion** and intends to improve the **testing capabilities**, besides the theoretical and simulation aspects.

CIRA IMP-EP program overview

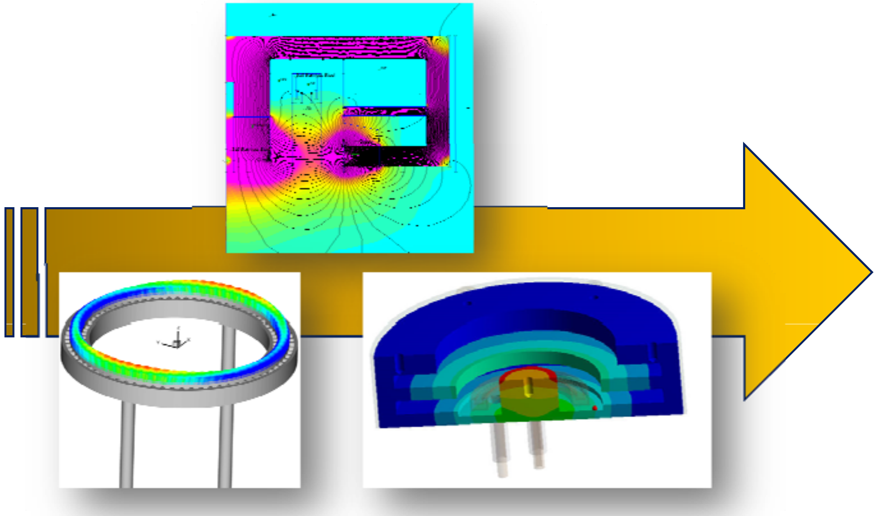
CIRA program on space electric propulsion[1] is divided in three main lines:



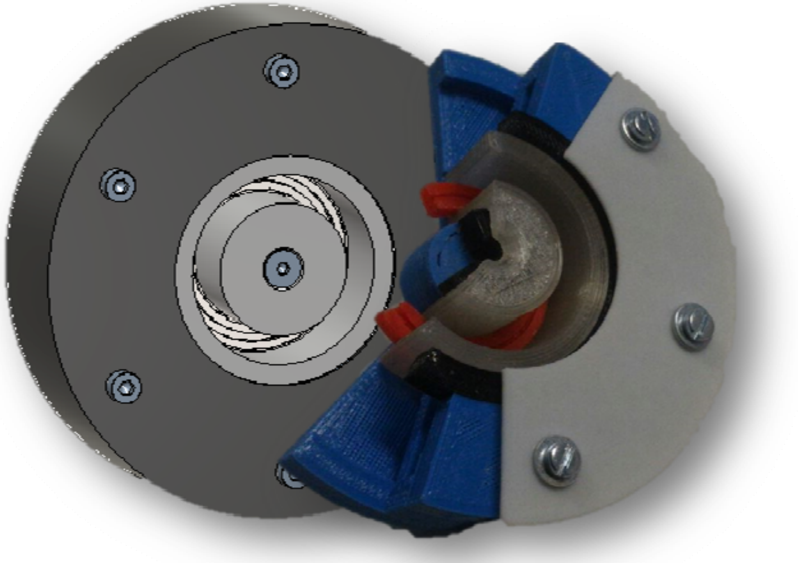
CIRHET-250
Experimental Hall Thruster

- The low power **Hall Effect Thrusters (HET)** will be tested in MSVC in order to set-up advanced diagnostic.
- **The low-power** HET, **CIRHET-250,** is in Preliminary Design Review Phase, and it has been designed according to HET scaling methodology*.
- The design of **CIRHET-250** has been preliminary verified by magnetic field, thermal and CFD analyses.

CIRHET-250[2]	
Nominal Discharge Power	**250 W**
Nominal Thrust	**11 mN**
Specific Impulse	**1250 s**
Propellant	**Xenon**
Cathode Location	**External**
Thruster Mass	**0.7 kg**



CIRHET-250 Mockup of the first concept design



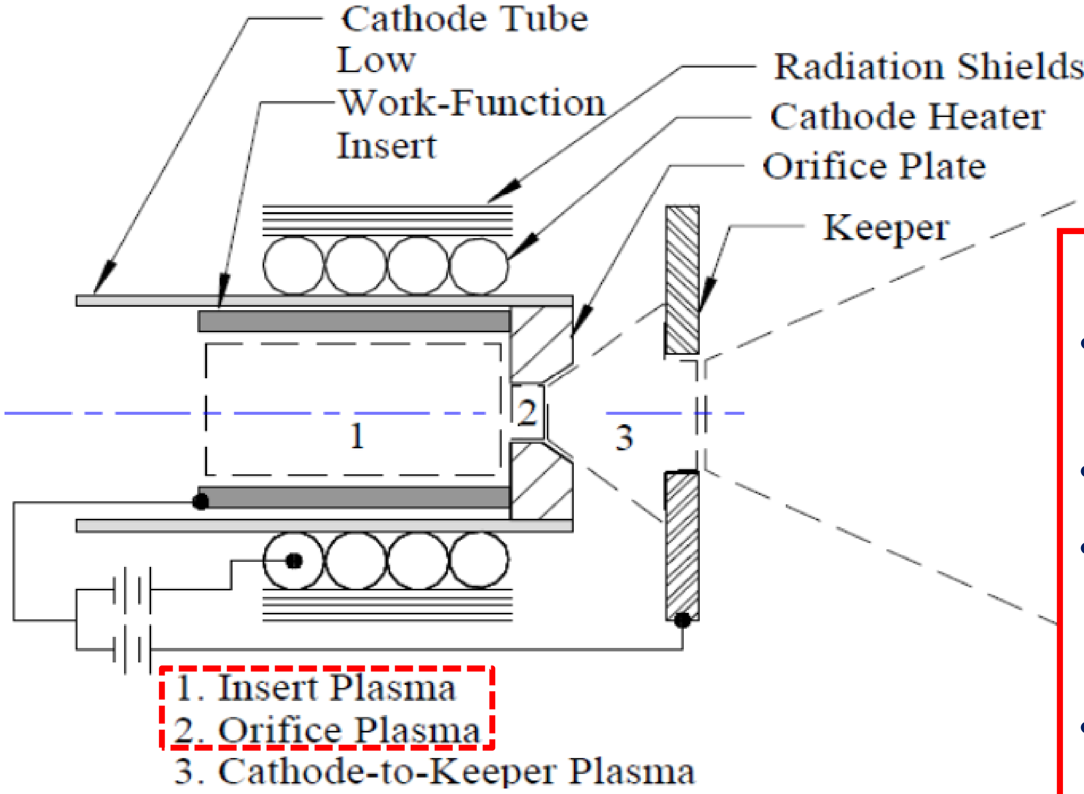
OHC Preliminary Design Tool - Description Model

A design tool for the cathode is necessary to develop the low power HET. In order to understand physical behavior and predict main design parameters, a simplified model has been developed.

A complete model of a thermionic hollow cathode requires:

- Plasma models (*Emitter insert region, Orifice region, Orifice-Keeper Region*)
- Thermal models

Actual version of the Tool

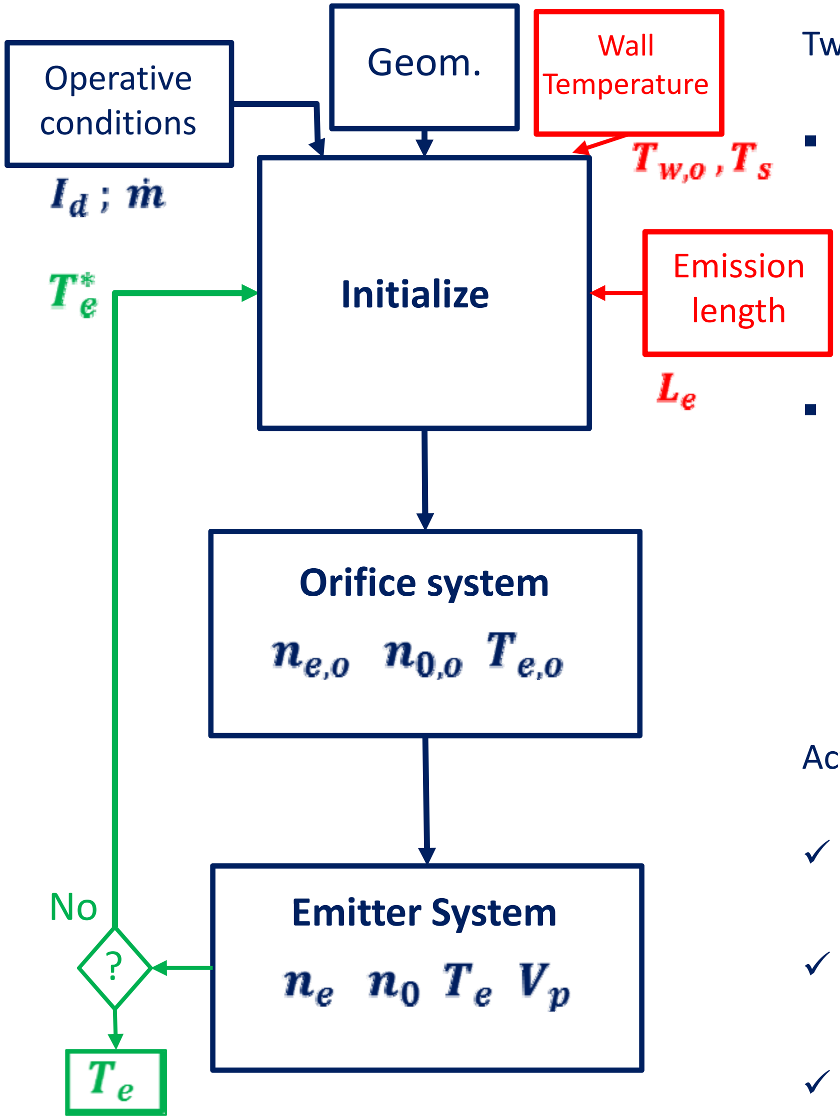


OHC- schematic and control volumes

Plasma Model Assumptions

- Properties averaged in each control volume
- Steady state condition
- Quasi-neutral plasma, mixture of three perfect gases (thermalized electrons, singly-charged positive ions, and neutrals)
- Ions and neutrals at the same temperature of the cathode wall.

OHC Preliminary Design Tool - Description
Plasma Model



Flow Chart of the OHC plasma model tool

Two systems have been solved, to obtain plasma parameters :

- Orifice Plasma
  - Pressure Equation
  - Ion Flux Balance
  - Internal Power Balance

  } $n_{e,o}$; $T_{e,o}$; $n_{0,o}$

- Insert Plasma
  - Plasma Pressure Equation
  - Ion Flux Balance
  - Current Density Balance
  - Plasma Power Balance

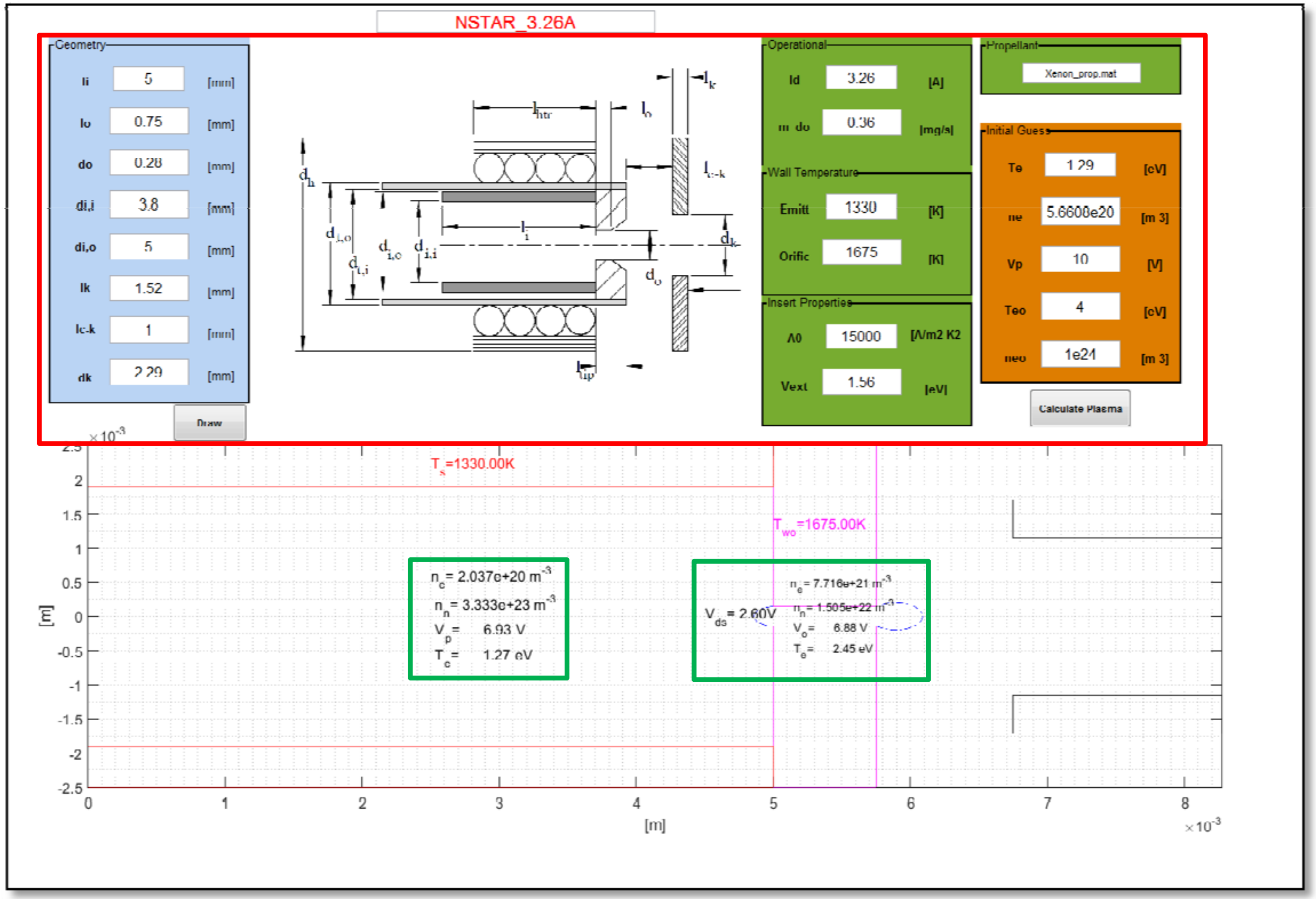
  } n_e ; T_e ; n_0 ; V_p

Actual version of the tool:

- ✓ Emission length (L_e), emitter (T_s) and orifice (T_{wo}) wall temperatures are input (**not updated**)
- ✓ Emitter electron temperature (T_e) is the convergence parameter which links the plasma models (**updated**)
- ✓ Verification of plasma conditions (Debye length, mean free paths calculations)

OHC Preliminary Design Tool - Description

MATLAB® GUI- Graphic User Interface



NSTAR_3.26A

Geometry

li	5	[mm]
lo	0.75	[mm]
do	0.28	[mm]
di,i	3.8	[mm]
di,o	5	[mm]
lk	1.52	[mm]
lc-k	1	[mm]
dk	2.29	[mm]

Operational

Id	3.26	[A]
m do	0.36	[mg/s]

Wall Temperature

Emitt	1330	[K]
Orific	1675	[K]

Insert Properties

A0	15000	[A/m2 K2]
Vext	1.56	[eV]

Propellant: Xenon_prop.mat

Initial Guess

Te	1.29	[eV]
ne	5.6600e20	[m 3]
Vp	10	[V]
Teo	4	[eV]
neo	1e24	[m 3]

T_s=1330.00K

T_{wo}=1675.00K

n_c= 2.037e+20 m^{-3}
n_n= 3.333e+23 m^{-3}
V_p= 6.93 V
T_e= 1.27 eV

V_{ds}= 2.60V
n_e= 7.716e+21 m^{-3}
n_n= 1.505e+22 m^{-3}
V_o= 6.88 V
T_e= 2.45 eV

CODE INPUT:

- Geometry
- Operational
  (I_d , m_{dot})
- Propellant Properties
- Insert Properties
  (Richardson-Dushman, work function)
- Starting plasma properties values
- Wall Temperatures
  (emitter , orifice)

CODE OUTPUT:

- Emitter Region Plasma Properties
- Orifice Region Plasma Properties

NEXT STEPS:

- Updating emission length and wall temperatures (thermal model)
- Orifice tip-keeper Region Plasma Properties Model

OHC Preliminary Design Tool - Validation

Literature Test Cases

Xenon Cathodes

Reference	NSTAR[3]	Wilbur-1984 [4]	Domonkos-1999 [5]	Albertoni-2013 [6]
Validation Plasma Region	*Orifice*	*Insert*	*Orifice + Insert*	*Orifice + Insert*
Available data	*Num.*	*Exp./Num.*	*Exp./Num.*	*Num.*
Insert internal diameter [mm]	3.8	3.8	1.22	3
Orifice length [mm]	0.75	1.22	0.71	0.36
Orifice Diameter [mm]	0.28	0.76	0.15	0.3
Mass flow rate, [mg/s]	0.36	0.127	[0.11 ÷ 0.23]	[0.3 ÷ 2]
Discharge Current [A]	3.26	[1.24 ÷ 4.26]	[0.75 ÷ 1.25]	[1 ÷ 3]
Insert Material	*Ba*	*Ta (dip-coated)*	*W (Doped)*	*LaB_6*
Richardson-Dushman cost. [10^4 A/m^2·K^2]	*1.5*	*120*	*60*	*29*
Work function [eV]	*1.56*	*2.25*	*2.3*	*2.66*

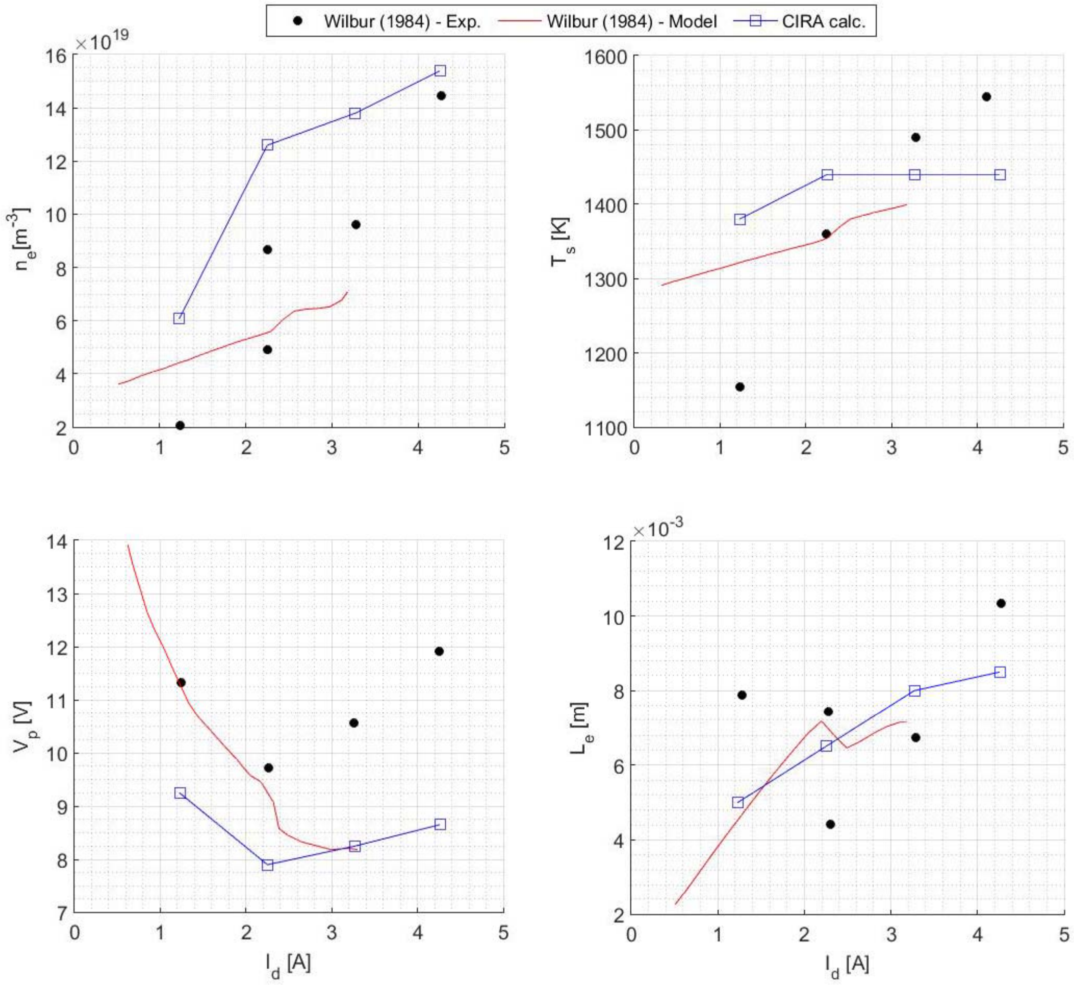
OHC Preliminary Design Tool - Validation

Orifice Plasma Model: NSTAR cathode

ORIFICE	**0-D model (CIRA calculation)**	0-D model (Mizrahi[7])	0-D model (Mandell and Katz[8])	0-D model (Korkmaz and Celik[9])	0-D model (Albertoni et al.[6])	1-D model (Katz et al.[10])			2-D model (Mikellides and Katz [11])		
Plasma parameter	**Average**	Average	Average	Average	Average	Orifice inlet	Maximum reached value	Orifice outlet	Orifice inlet	Maximum reached value	Orifice outlet
$n_0 (10^{23}\ m^{-3})$	**0.15**	1.1	0.4	0.6	0.2	2.8	2.8	0.6	0.65	0.65	0.1
$n_e (10^{22}\ m^{-3})$	**0.77**	2.7	1	0.7	0.7	2.8	6	1.8	2	2.2	0.5
T_e (eV)	**2.45**	1.6	2.2	2.4	2.7	1.2	1.8	1.8	2	2.2	2.2
$n_e/(n_e+n_0)$	**0.34**	0.2	0.18	0.1	0.24	0.09	0.24	0.23	0.23	0.5	0.33

- Electron temperature and density close to Albertoni[6] and Korkmaz[9] computations by an error less than 10%; neutral density is underestimated.
- Higher electron temperature along with lower plasma and neutral densities with respect to the predictions of the 0-D model by Mizrahi[7], and the 0-D model by Mandell and Katz[8] (this two models include the energy loss due to excitation events in the plasma energy balance, neglected in the present study).
- Better accordance with the values predicted by the 2-D model of Mikellides and Katz[11] at the orifice outlet.

OHC Preliminary Design Tool - Validation
Insert Plasma Model: Wilbur cathode



Model Parameter	Code Input	Code Output
Wilbur	T_e	L_e, T_s V_p, n_e
CIRA	L_e, T_s	T_e V_p, n_e

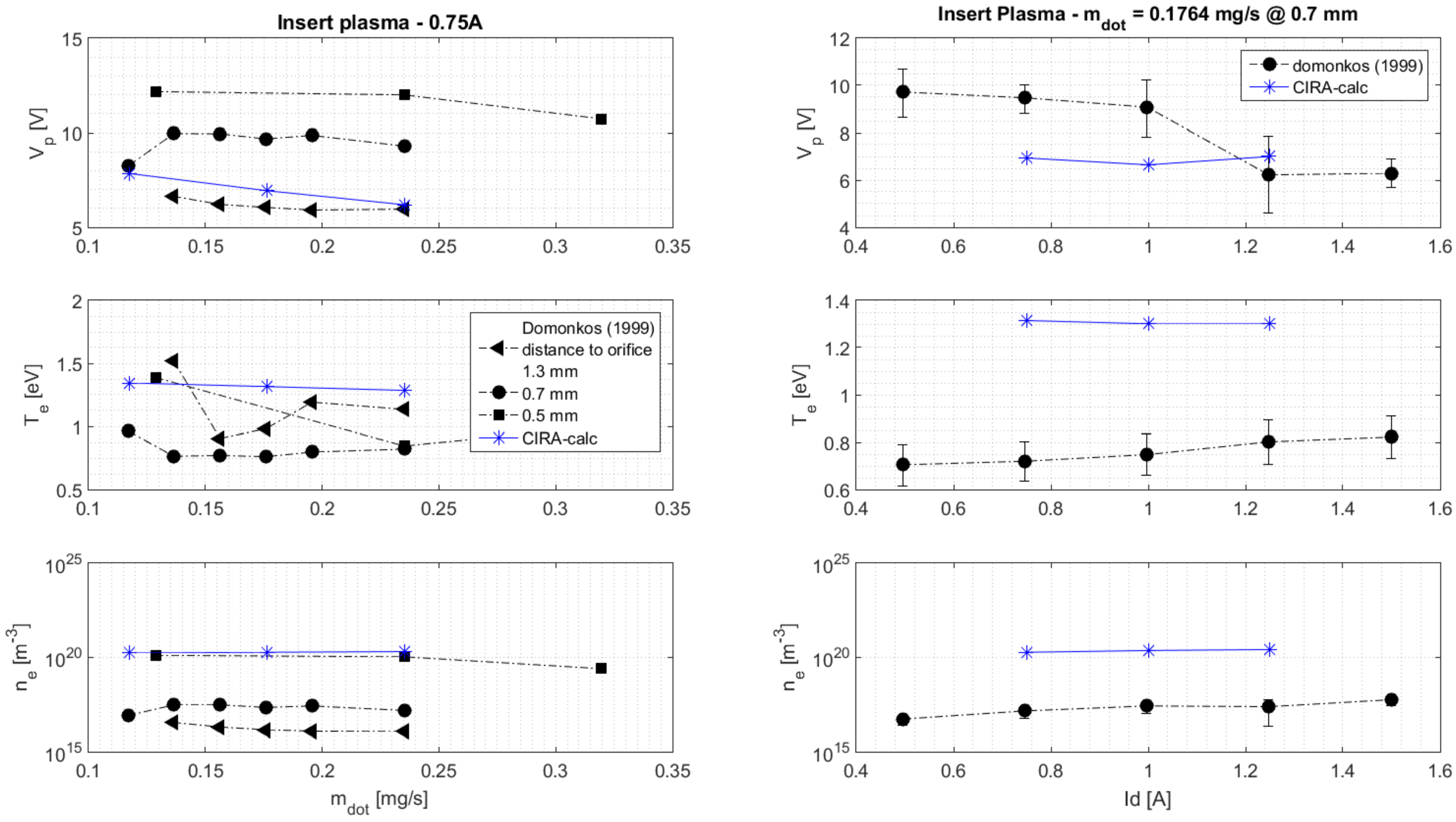
Experimental and Numeric Data

Wilbur [4]

- Trends are well predicted (particularly those of plasma potential)
- With respect to Exp. Data: Overestimation of electron density; underestimation of Plasma potential
- Average wall temperature level in line with respect to Exp. Data and close to numerical data
- Emission Length increases with current and match the numeric data very well (almost whitin exp. Data)

OHC Preliminary Design Tool - Validation

Insert Plasma Model: Domonkos cathode

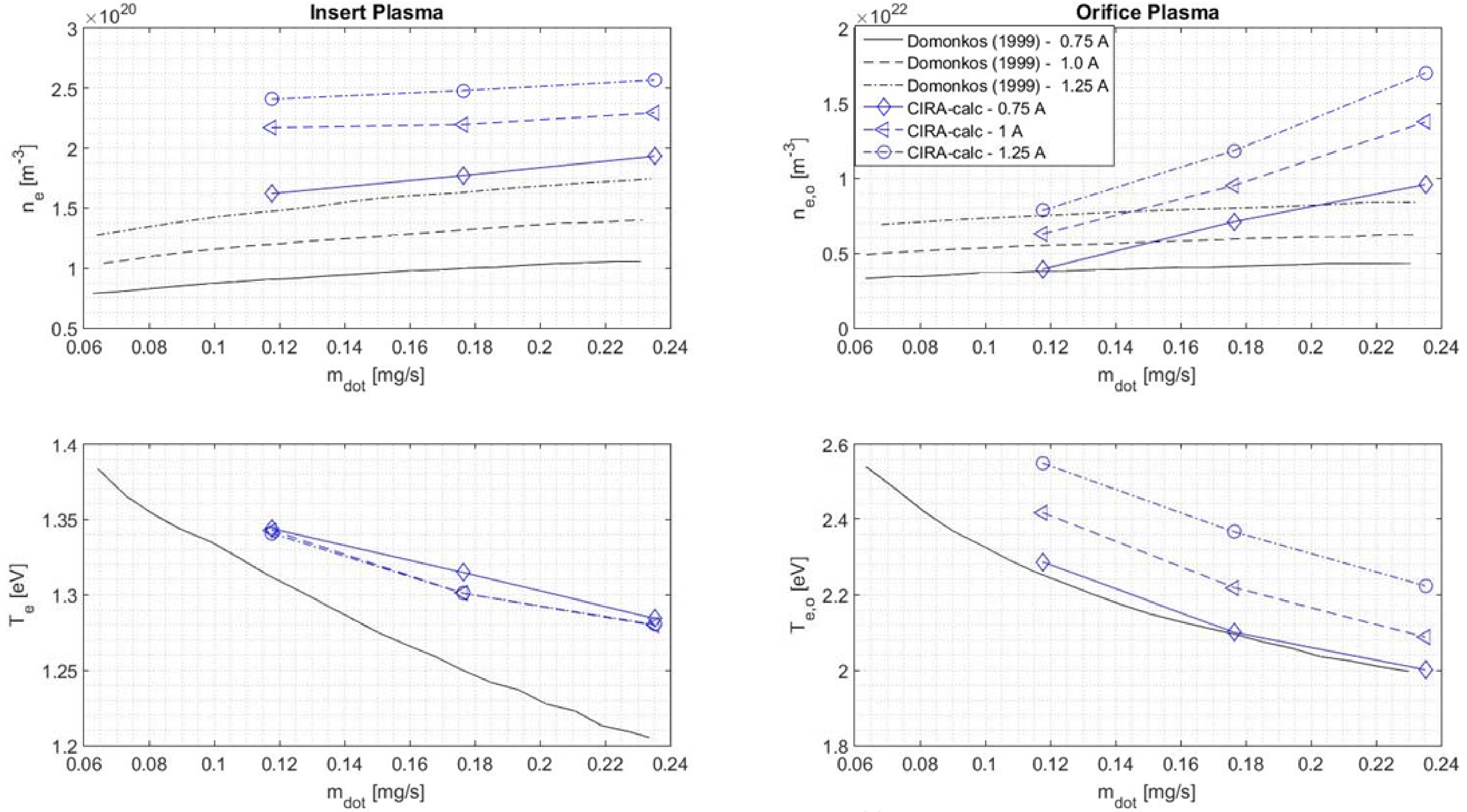


Experimental Data – Domonkos [5]

- Trends well predicted
- Calculations close to experimental data (1.3mm distance to orifice @ 0.75A) except for electron density

OHC Preliminary Design Tool - Validation

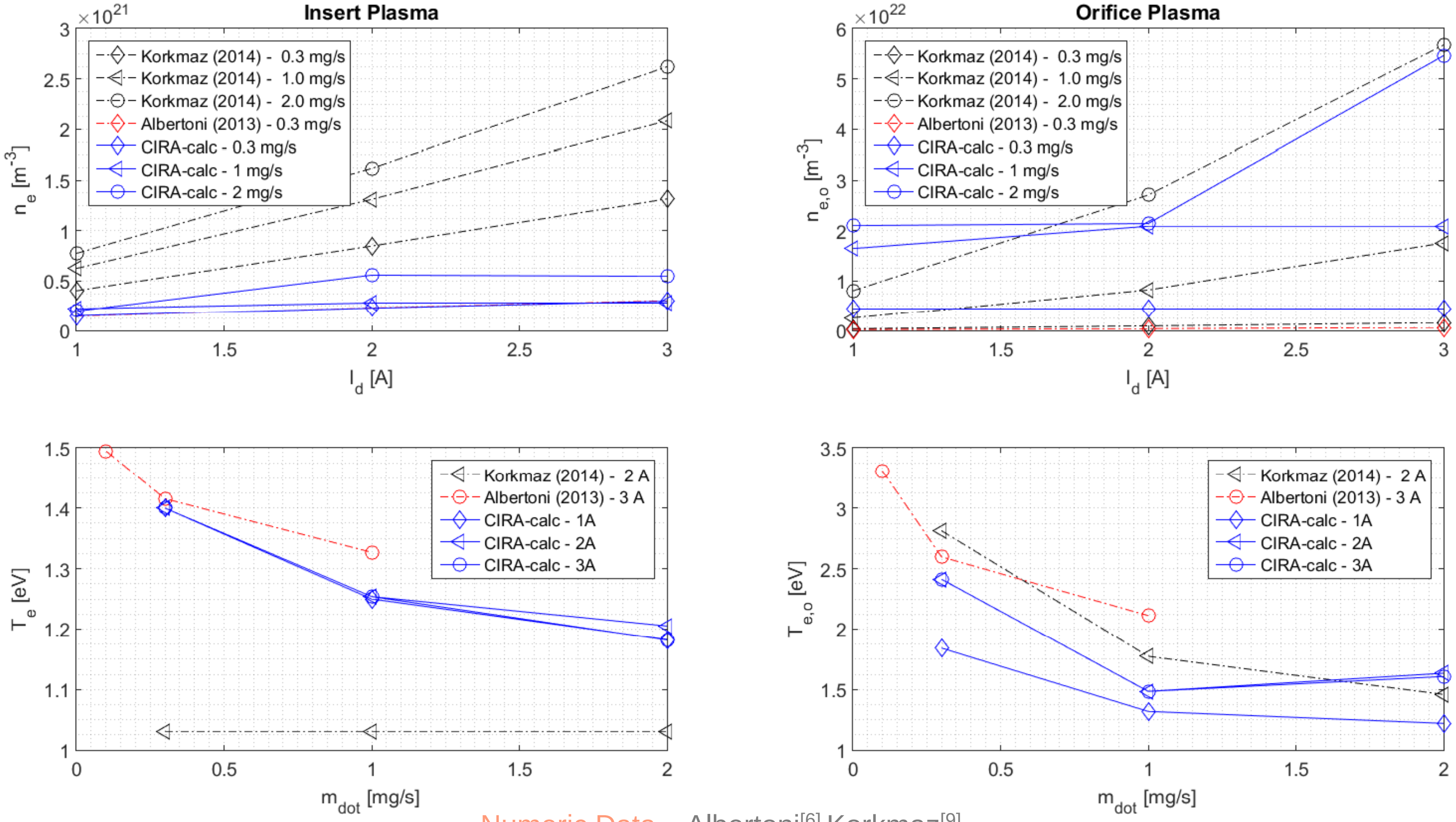
Insert and Orifice Plasma Model: Domonkos cathode



Numeric Data – Domonkos[5]

- Trends are well predicted
- Orifice electron temperature changes with current (trend not detected by Domonkos)
- Slight overestimation of electron number densities in insert and orifice regions

OHC Preliminary Design Tool - Validation
Insert and Orifice Plasma Model: Albertoni cathode



Numeric Data – Albertoni[6] Korkmaz[9]

- Trends well predicted for every case
- Insert region: Electron number density overlapped to Albertoni[6] calculation;
- Orifice region: Electron number density close to Korkmaz[9] data (except for 0.3mg/s test case);

Conclusion & Future Development

CONCLUSIONS

- ✓ *CIRA is expanding its testing capabilities with two new facilities for Electric Propulsion: MSVC (<5kW, by 2018) and LSVC (>5kW, by 2020)*
- ✓ *CIRA has started, from 2015, the acquisition of basic research competences and engineering design skills on EP devices*
- ✓ ***A reduced-order numerical model describing the insert's and orifice's plasmas in an orificed hollow cathode has been developed as a quick tool for the design of thermionic cathodes.** In this preliminary implementation walls' temperatures and emission length are imposed.*
- ✓ ***The results of the validation tests have been shown. They are in good agreement with both theoretical and experimental trends found in the literature**.*

FUTURE DEVELOPMENTS

- ➢ *Dedicated Thermal model implementation: evaluation of the heat transfer mechanisms and the related temperature gradients along the cathode*
- ➢ *Modelling of plasma in the near tip cathode region*
- ➢ *Emission length updating*
- ➢ *Preliminary design of a specific cathode for the developed thruster (CIRHET-250)*
- ➢ *Experimental test campaign: validation of the tool (scheduled by the first half of 2018)*

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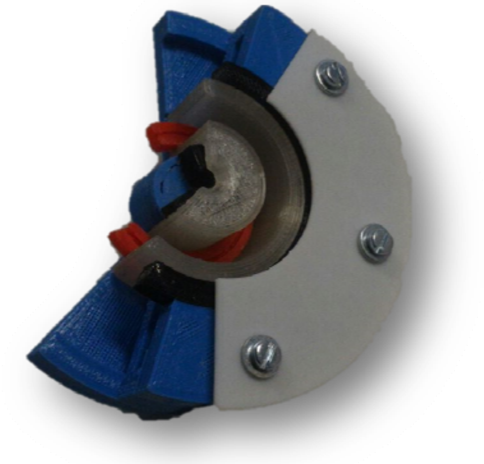
Thanks for your attention



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