# CEA software study of the VINCI engine installed on the Arianne 6 in hp condition

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**ABSTRACT** In this paper a CEA analysis of the VINCI engine is presented. Vinci is the most recent generation of cryogenic upper-stage engines for space launch launchers.It contributes significantly to Ariane's performance, sending a payload of 10.5 tonnes to GTO in the Ariane 64 version while allowing the development of optimized injection techniques for all Ariane 6 flights. It's intended to be simple to put together and use. ArianeGroup is developing it in collaboration with European partners as part of an ESA initiative.. Using the data available on ESA website, it was possible to evaluate the ideal operating condition for the engine. Furthermore, the output results of the software have been compared to the theoretical ones.

**KEYWORDS** *Ariane 6, CEA, Thermal Analysis, Vinci Engine*

## I. INTRODUCTION - ARIANE 6

*Ariane 6* is an innovative launcher that will replace Ariane 5 in 2023. One of the aims of the project is to create a launcher that allows direct insertion into geostationary orbit, reducing orbital transfer times. Among the various engines installed in the launcher, it is worth mentioning *VINCI*, the first European engine with expansion cycle, which will power *the upper stage* of Ariane 6. [1] It is powered by liquid oxygen-hydrogen and can be re-ignited up to five times. This increases the operational flexibility of Ariane 6 and ensures that the engine deorbit safely at the end of the mission. This engine was tested more than 140 times and re-ignited several times in succession in near vacuum to complete its certification, reporting a total of more than 14 hours of operation.

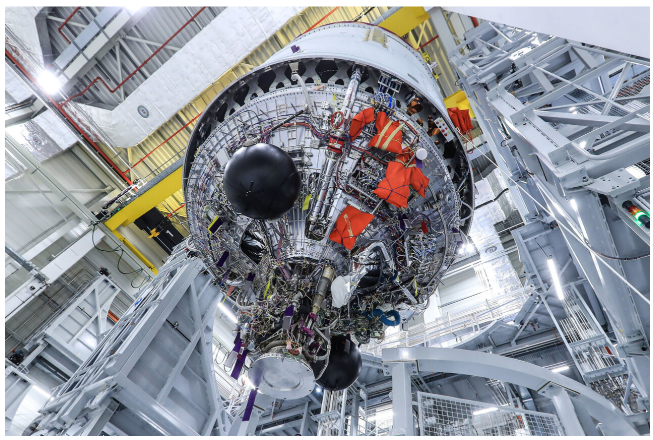

Figure 1: Ariane 6 upper stage being prepared for hot-fire tests [3]

## II. CASE STUDY AND SOFTWARE IMPLEMENTATION

In setting up the *hp* problem with the aim of going to calculate the *adiabatic combustion temperature*, we are essentially exploiting the software's ability to solve the problem of $p+1$ equations. We assign the initial conditions, initial pressure and initial concentrations, and solve the problem under the assumption that the initial enthalpy remains constant.

## III. RESULTS

As predicted also by the data we had available, it can be seen that the ratio leading to the maximum temperature is the one corresponding to OF equal to 8 since one mole of hydrogen requires half a mole of oxygen, so for every 16 grams of oxygen 2 grams of hydrogen are needed. In spite of this, as the cycle is closed, we still have to respect the turbine limit temperatures so the mixing ratio is about 6.

Using the results obtained from the code, it is possible to plot the temperature and concentration trends as a function of OF.

| VINCI | |
|---|---|
| Fuel | Liquid Hydrogen *[LH2]* |
| Oxidizer | Liquid Oxygen *[LOX]* |
| OF | 6.1 |
| Combustion chamber pressure | 60 atm |

Table 1: Essential data for the development of the paper [2]

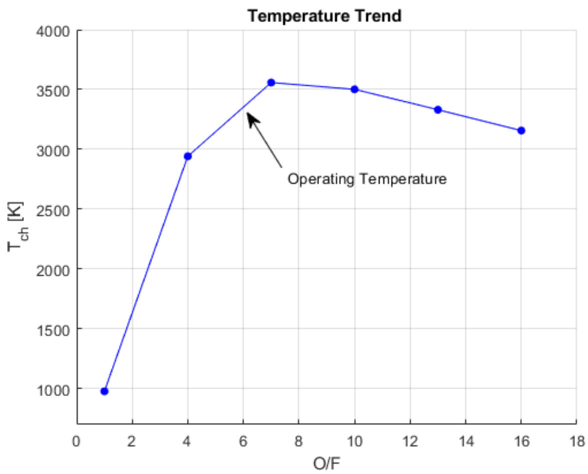


Figure 2: Temperature trend plot

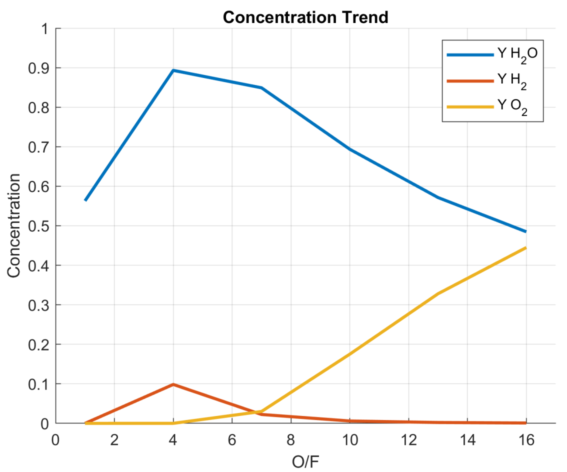


Figure 3: Concentration temperature plot

## APPENDIX. CEA

Listing 1: CEA Listing

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        NASA-GLENN CHEMICAL EQUILIBRIUM PROGRAM CEA2, FEBRUARY 5, 2004
                  BY  BONNIE MCBRIDE AND SANFORD GORDON
     REFS: NASA RP-1311, PART I, 1994 AND NASA RP-1311, PART II, 1996

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### CEA analysis performed on Tue 04-May-2021 13:23:56

# Problem Type: "Assigned Enthalpy and Pressure"

prob case=Vinci_propeller7920 hp

# Pressure (1 value):
p,atm= 60

# Oxidizer/Fuel Wt. ratio (6 values):
o/f= 1, 4, 7, 10, 13, 16

# You selected the following fuels and oxidizers:
reac
fuel H2(L)               wt%=100.0000
oxid O2(L)               wt%=100.0000

# You selected these options for output:
# short version of output
output short
# Proportions of any products will be expressed as Mass Fractions.
output massf
# Heat will be expressed as siunits
output siunits

# Input prepared by this script:/var/www/sites/cearun.grc.nasa.gov/cgi-bin/CEARU
N/prepareInputFile.cgi

### IMPORTANT:  The following line is the end of your CEA input file!
end


        THERMODYNAMIC EQUILIBRIUM COMBUSTION PROPERTIES AT ASSIGNED

                                  PRESSURES

CASE = Vinci_propeller

             REACTANT                    WT FRACTION      ENERGY      TEMP
                                          (SEE NOTE)     KJ/KG-MOL      K
FUEL         H2(L)                        1.0000000     -9012.000     20.270
OXIDANT      O2(L)                        1.0000000    -12979.000     90.170

O/F=    1.00000  %FUEL= 50.000000  R,EQ.RATIO= 7.936683  PHI,EQ.RATIO= 7.936683

THERMODYNAMIC PROPERTIES

P, BAR            60.795
T, K              977.49
RHO, KG/CU M    3.0159 0
H, KJ/KG        -2438.06
U, KJ/KG        -4453.89
G, KJ/KG        -37078.1
S, KJ/(KG)(K)    35.4378
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```
M, (1/n)            4.032
(dLV/dLP)t       -1.00000
(dLV/dLT)p         1.0000
Cp, KJ/(KG)(K)     7.8107
GAMMAs             1.3587
SON VEL,M/SEC      1655.0

MASS FRACTIONS

*H2               0.43700
H2O               0.56300

 * THERMODYNAMIC PROPERTIES FITTED TO 20000.K

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS


        THERMODYNAMIC EQUILIBRIUM COMBUSTION PROPERTIES AT ASSIGNED

                                  PRESSURES

CASE = Vinci_propeller

            REACTANT                    WT FRACTION      ENERGY      TEMP
                                         (SEE NOTE)     KJ/KG-MOL      K
FUEL        H2(L)                        1.0000000     -9012.000     20.270
OXIDANT     O2(L)                        1.0000000    -12979.000     90.170

O/F=    4.00000  %FUEL= 20.000000  R,EQ.RATIO= 1.984171  PHI,EQ.RATIO= 1.984171

THERMODYNAMIC PROPERTIES

P, BAR             60.795
T, K              2942.02
RHO, KG/CU M    2.4849 0
H, KJ/KG         -1218.59
U, KJ/KG         -3665.17
G, KJ/KG         -64689.9
S, KJ/(KG)(K)     21.5741

M, (1/n)            9.998
(dLV/dLP)t       -1.00407
(dLV/dLT)p         1.0813
Cp, KJ/(KG)(K)     6.0150
GAMMAs             1.1870
SON VEL,M/SEC      1704.2

MASS FRACTIONS

*H                0.00119
*H2               0.09845
H2O               0.89317
*O                0.00009
*OH               0.00703
*O2               0.00007

 * THERMODYNAMIC PROPERTIES FITTED TO 20000.K

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS


        THERMODYNAMIC EQUILIBRIUM COMBUSTION PROPERTIES AT ASSIGNED

                                  PRESSURES

CASE = Vinci_propeller
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```
            REACTANT                    WT FRACTION      ENERGY      TEMP
                                         (SEE NOTE)     KJ/KG-MOL      K
FUEL        H2(L)                        1.0000000     -9012.000     20.270
OXIDANT     O2(L)                        1.0000000    -12979.000     90.170

O/F=    7.00000  %FUEL= 12.500000  R,EQ.RATIO= 1.133812  PHI,EQ.RATIO= 1.133812

THERMODYNAMIC PROPERTIES

P, BAR            60.795
T, K             3558.09
RHO, KG/CU M    3.0556 0
H, KJ/KG         -913.72
U, KJ/KG        -2903.37
G, KJ/KG        -60320.0
S, KJ/(KG)(K)    16.6961

M, (1/n)          14.869
(dLV/dLP)t      -1.03945
(dLV/dLT)p        1.6891
Cp, KJ/(KG)(K)   10.2584
GAMMAs            1.1313
SON VEL,M/SEC     1500.3

MASS FRACTIONS

*H               0.00238
HO2              0.00022
*H2              0.02248
H2O              0.84907
H2O2             0.00005
*O               0.00929
*OH              0.08637
*O2              0.03013

 * THERMODYNAMIC PROPERTIES FITTED TO 20000.K

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS


        THERMODYNAMIC EQUILIBRIUM COMBUSTION PROPERTIES AT ASSIGNED

                                  PRESSURES

CASE = Vinci_propeller

            REACTANT                    WT FRACTION      ENERGY      TEMP
                                         (SEE NOTE)     KJ/KG-MOL      K
FUEL        H2(L)                        1.0000000     -9012.000     20.270
OXIDANT     O2(L)                        1.0000000    -12979.000     90.170

O/F=   10.00000  %FUEL=  9.090909  R,EQ.RATIO= 0.793668  PHI,EQ.RATIO= 0.793668

THERMODYNAMIC PROPERTIES

P, BAR            60.795
T, K             3501.53
RHO, KG/CU M    3.7772 0
H, KJ/KG         -775.14
U, KJ/KG        -2384.66
G, KJ/KG        -50619.8
S, KJ/(KG)(K)    14.2351

M, (1/n)          18.088
(dLV/dLP)t      -1.03358
(dLV/dLT)p        1.6024
Cp, KJ/(KG)(K)    7.9036
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```
GAMMAs              1.1309
SON VEL,M/SEC      1349.1

MASS FRACTIONS

*H                0.00099
HO2               0.00072
*H2               0.00602
H2O               0.69355
H2O2              0.00011
*O                0.01766
*OH               0.10582
*O2               0.17514

 * THERMODYNAMIC PROPERTIES FITTED TO 20000.K

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS


        THERMODYNAMIC EQUILIBRIUM COMBUSTION PROPERTIES AT ASSIGNED

                                  PRESSURES

CASE = Vinci_propeller

            REACTANT                    WT FRACTION      ENERGY      TEMP
                                         (SEE NOTE)     KJ/KG-MOL      K
FUEL        H2(L)                        1.0000000     -9012.000     20.270
OXIDANT     O2(L)                        1.0000000    -12979.000     90.170

O/F=   13.00000  %FUEL=  7.142857  R,EQ.RATIO= 0.610514  PHI,EQ.RATIO= 0.610514

THERMODYNAMIC PROPERTIES

P, BAR              60.795
T, K               3331.23
RHO, KG/CU M    4.4597 0
H, KJ/KG           -695.96
U, KJ/KG          -2059.17
G, KJ/KG          -43173.4
S, KJ/(KG)(K)      12.7513

M, (1/n)            20.318
(dLV/dLP)t        -1.01995
(dLV/dLT)p          1.3857
Cp, KJ/(KG)(K)      5.6228
GAMMAs              1.1361
SON VEL,M/SEC      1244.5

MASS FRACTIONS

*H                0.00037
HO2               0.00085
*H2               0.00220
H2O               0.57136
H2O2              0.00011
*O                0.01452
*OH               0.08255
*O2               0.32804

 * THERMODYNAMIC PROPERTIES FITTED TO 20000.K

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS


        THERMODYNAMIC EQUILIBRIUM COMBUSTION PROPERTIES AT ASSIGNED
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                                  PRESSURES

CASE = Vinci_propeller

            REACTANT                    WT FRACTION      ENERGY      TEMP
                                         (SEE NOTE)     KJ/KG-MOL      K
FUEL        H2(L)                        1.0000000     -9012.000     20.270
OXIDANT     O2(L)                        1.0000000    -12979.000     90.170

O/F=   16.00000  %FUEL=  5.882353  R,EQ.RATIO= 0.496043  PHI,EQ.RATIO= 0.496043

THERMODYNAMIC PROPERTIES

P, BAR            60.795
T, K             3156.94
RHO, KG/CU M    5.0902 0
H, KJ/KG         -644.72
U, KJ/KG        -1839.08
G, KJ/KG        -37757.4
S, KJ/(KG)(K)    11.7559

M, (1/n)          21.977
(dLV/dLP)t      -1.01216
(dLV/dLT)p        1.2536
Cp, KJ/(KG)(K)    4.3230
GAMMAs            1.1433
SON VEL,M/SEC     1168.6

MASS FRACTIONS

*H               0.00015
HO2              0.00077
*H2              0.00093
H2O              0.48477
H2O2             0.00009
*O               0.00974
*OH              0.05858
*O2              0.44497
O3               0.00001

 * THERMODYNAMIC PROPERTIES FITTED TO 20000.K

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS
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## References

[1] Alliot, Patrick, Christian Fiorentino, and Emmanuel Edeline, *"Progress of the VINCI engine system development"*, 47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit. 2010.

[2] Sippel, Martin, Etienne Dumont, and Ingrid Dietlein, *"Investigations of future expendable launcher options."*, Space Launcher Systems Analysis (SART), DLR, Bremen, Germany

[3] Alliot, Patrick J., Jean-Francois Delange, and Anne Lekeux, *"VINCI, the European reference for Ariane 6 upper stage cryogenic propulsive system."* 51st AIAA/SAE/ASEE Joint Propulsion Conference. 2015.

[4] Muhalim, Noor Muhammad Feizal B., and Subramaniam Krishnan, *"Design Of Nitrogen-Tetroxide/Monomethyl-Hydrazine Thruster For Upper Stage Application"*, Department of Aeronautical Engineering, Faculty of Mechanical Engineering Universiti Teknologi Malaysia, 81310 Skudai, Malaysia