Convective Heating of the LIFE Engine Target During Injection

UCSD Jacobs | Mechanical and Aerospace Engineering

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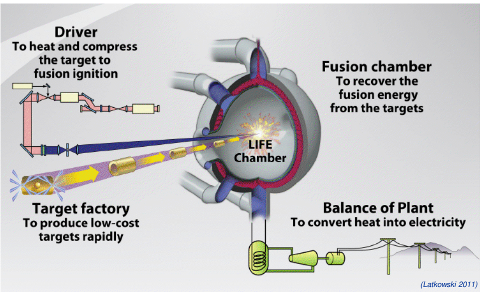
Laser Inertial Fusion Energy (LIFE):



- •A rep rate of 10-20 Hz is required for adequate power generation
- •Chamber gas can be considered viscous (CFD ok), but density is low enough a direct simulation Monte Carlo (DSMC) solution is tractable on a PC platform

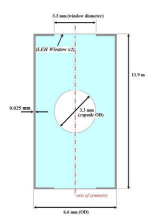
Design Requirement:

- •Melting of either the DT ice or laser entrance hole (LEH) window constitutes target failure and no burn

Target Evolution has been Investigated:

Target flight conditions (TFC):

	New and Old TFC *(same from Nov. 09' to Dec 10')*	
Hohlraum LEH window thickness	0.5 µm	
Hohlraum wall material	Lead	
Chamber gas	Xenon	
Internal hohlraum gas	Helium	
Initial internal hohlraum gas density	1 mg/cc	
Target spin rate	15,000 RPM	
	Old TFC *(valid Nov. 09')*	New TFC *(valid Dec. 10')*
Hohlraum radius, OD	6.6 mm	9.9 mm
Hohlraum length	11.9 mm	15.4 mm
Hohlraum wall thickness	25 µm	*(variable, see Figure 2.3)*
Hohlraum LEH window material	Polyimide (Kapton)	graphene
Chamber gas temperature	1000 K	8000 K
Chamber gas density	2.00×10^{22} /m^3	2.75×10^{22} /m^3
Chamber gas pressure at T_g	276 Pa *(2.1 torr)*	3037 Pa *(23 torr)*
Target injection velocity	200 m/s	250 m/s
Target transit distance in gas *(chamber radius)*	5 m	6 m
Initial target temperature	20 K	17 K
Initial internal target gas pressure	35,300 Pa	41,500 Pa

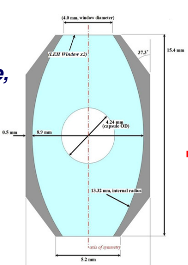


NIF-like hohlraum:

Note: P2 shields, tent and fuel capsule have been omitted from schematic

Dimensionless variables indicate highly compressible, laminar flow:

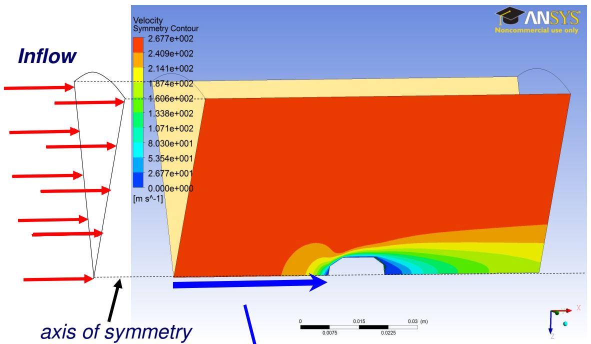
Dimensionless Variable	Formulation	Old TFC	New TFC
Reynold's number (Re)	$= (\rho v d)/\mu$	92	60
Mach number (Ma)	$= v/a = v/(\gamma RT)^{1/2}$	0.62	0.27
Knudsen number (Kn)	$= \lambda/d$	0.0082	0.0065
Prandtl number (Pr)	$= (C_p\mu)/k$	0.67	0.67



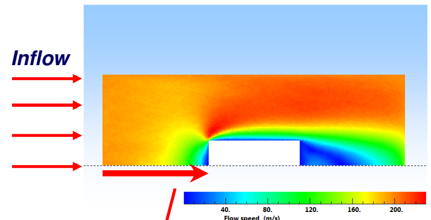
LIFE.2 hohlraum:

Comparison of Results of CFD and DSMC:

CFD: Velocity distribution for LIFE.2 hohlraum using ***ANSYS***

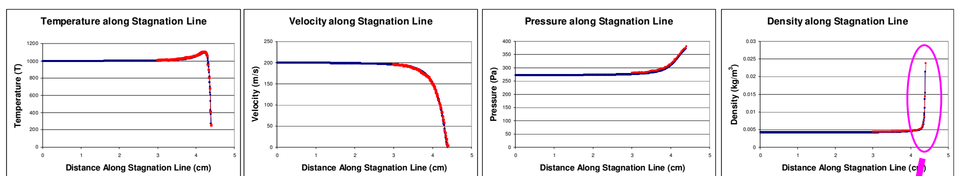


DSMC: Velocity distribution for NIF-like hohlraum using ***DS2V***

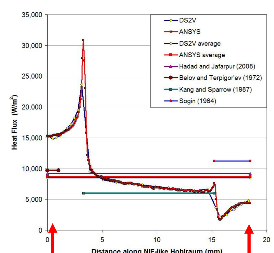


(ANSYS in BLUE) ***Flow properties along stagnation line*** ***(DS2V in RED)***

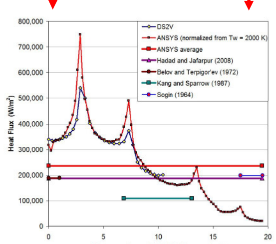
(for NIF-like hohlraum / old TFC)



Heat flux along hohlraum bodies:



windward center ***leeward center***



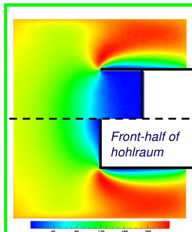
- •Heat transfer along hohlraum's body predicted well by ANSYS and DS2V with following correlations:
  - •Yaser et al (2008)
  - •Belov and Terpigor'ev (1969)
  - •Kang and Sparrow (1987)
  - •Whitaker (1972) - *sphere*
  - •Cohen (1961) - *sphere*
- •Changes in shape, temperature, target velocity, chamber temperature and density have increased heat transfer to target
- •Further *optimization* of hohlraum's shape is possible to mitigate convective heating along sensitive LEH window

From Bird (1994):

- •Overall Kundsen number can be misleading
- •Suggests using a 'local Knudsen number,' Kn*, where the characteristic length is the scale length of macroscopic gradients (such as density):

$$Kn^* = \lambda/L = (\lambda/\rho)(d\rho/dx)$$

- •Errors in Navier-Stokes result for Kn* above 0.1 and is hardly usable for Kn* above 0.2
- •A maximum Kn* of 0.17 was found, suggesting the continuum models are beginning to break down

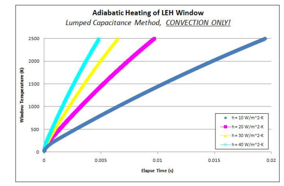


- •Inclusion of baffles has shown to reduce the heat transfer to the LEH windows as much as *8.5x* for the original target flight conditions
- •Heat is forced to conduct through large stagnation region, mitigating convective heating effects to sensitive LEH window

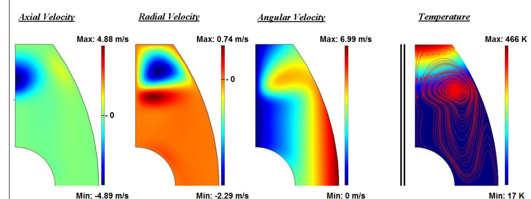
DS2V velocity comparison with (top) and without (bottom) baffles

Internal Transient Heating Analysis:

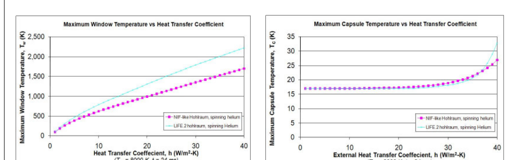
- •Adiabatic heating using lumped capacitance method shows the 0.5 µm thick LEH window has very little thermal resistance



- •The combination of target spinning and heating through the LEH windows induce buoyancy driven swirling effects, cooling the window and heating the capsule



- •The temperature of the LEH windows steadily increased as a function of heat transfer coefficient, h, over windows
- •Helium near the capsule rises less than 1 K for h less than 27 W/m²-K



Conclusions and Recommendations:

- •Changes in shape, temperature, target velocity, chamber temperature and density have increased heat transfer to the target
- •Careful comparison of DS2V and ANSYS viscous and thermal boundary layers where shown to have excellent agreement, with simulated heat fluxes varying less than 8% on average over the hohlraum's surface
- •Inclusion of baffles will dramatically decrease heat transfer to LEH windows
- •Internal helium acts as a heat sink to cool the LEH windows and heat fuel capsule
- •Testing is warranted once final conditions have been set