
# CFD in Automotive Exterior Lighting

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**North American Car Group - General Motors**

STAR-CD North American Users' Conference

May 1-2, 2000


# Acknowledgements


- GM
  - K. Elankumaran, VSAS
  - Dan Simon, IR LAB
  - Ron Hartfelder, Electrical Center
  - Jason Chu, Validation

- adapco


# Presentation Outline

- Background and Motivation
- Overview of the Analysis Models
  - Fog Lamp (Airflow and Temperature Distribution)
    - Model Schematic
    - Analysis Overview
    - Results
  - Headlamp (Condensation Removal from the Lamp Enclosure)
    - Model Schematic
    - Test Procedure
    - Analysis Overview, including Evaporation Model
    - Results
- Closing Remarks

# Background and Motivation

- Two important issues in evaluating the design of a lamp assembly are:
  - Thermal Management of the Heat Generated inside the Lamp

    Warpage, sagging, or bubbling may occur on various surfaces of the lamp enclosure if the temperature on these surfaces exceed the heat deflection temperature of the respective material. Therefore, identification of potential thermal problems (before prototype hardware is developed) is critical for optimum selection of various materials.
  - Moisture Entrapment, and Its Condensation and Removal from the Lamp Enclosure

    Condensation occurs when the moist air present in the lamp comes in contact with the regions on interior surfaces of the lamp that are below the saturation temperature of the surrounding air-water mixture. Water film detracts from vehicle appearance and illumination performance.

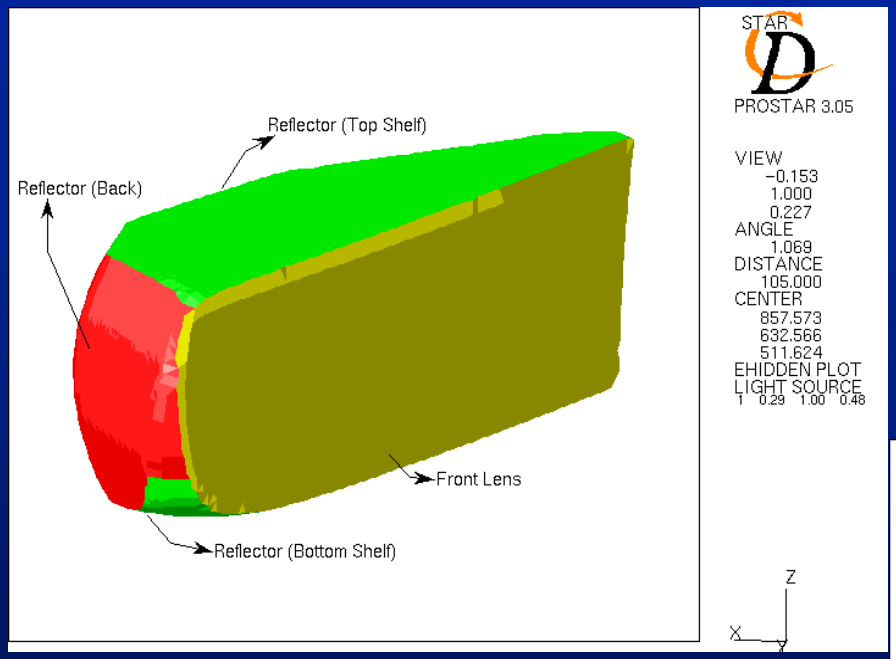
# Background and Motivation (cont…..d)

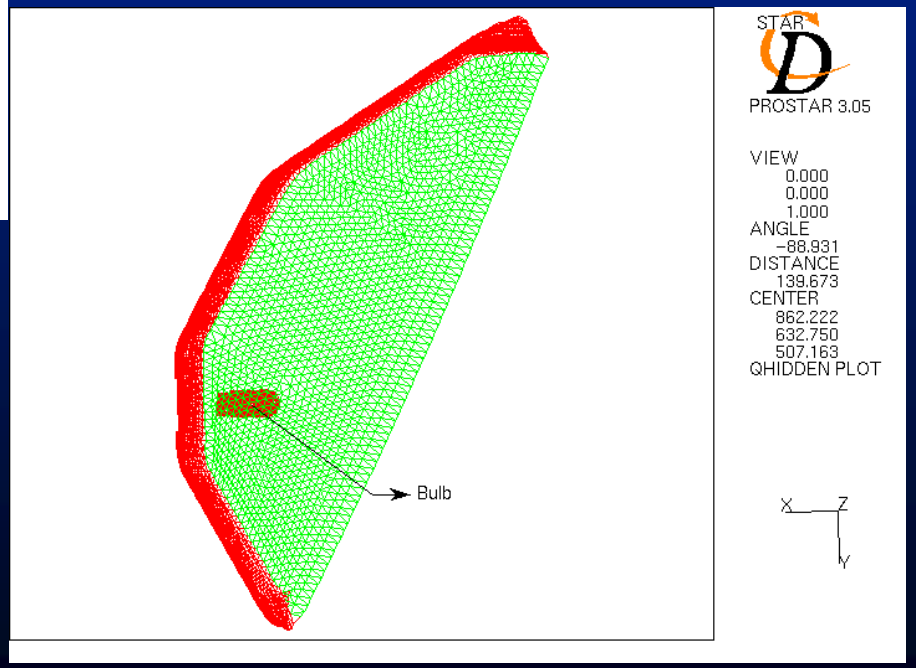
- Temperature distribution on the lamp walls as well as the formation of condensation and its removal are dependent on combined heat, mass, and momentum transport processes that occur inside a lamp.

- CFD-based simulation models (when appropriately developed and validated) can play a significant role in the lamp development process by ways of:

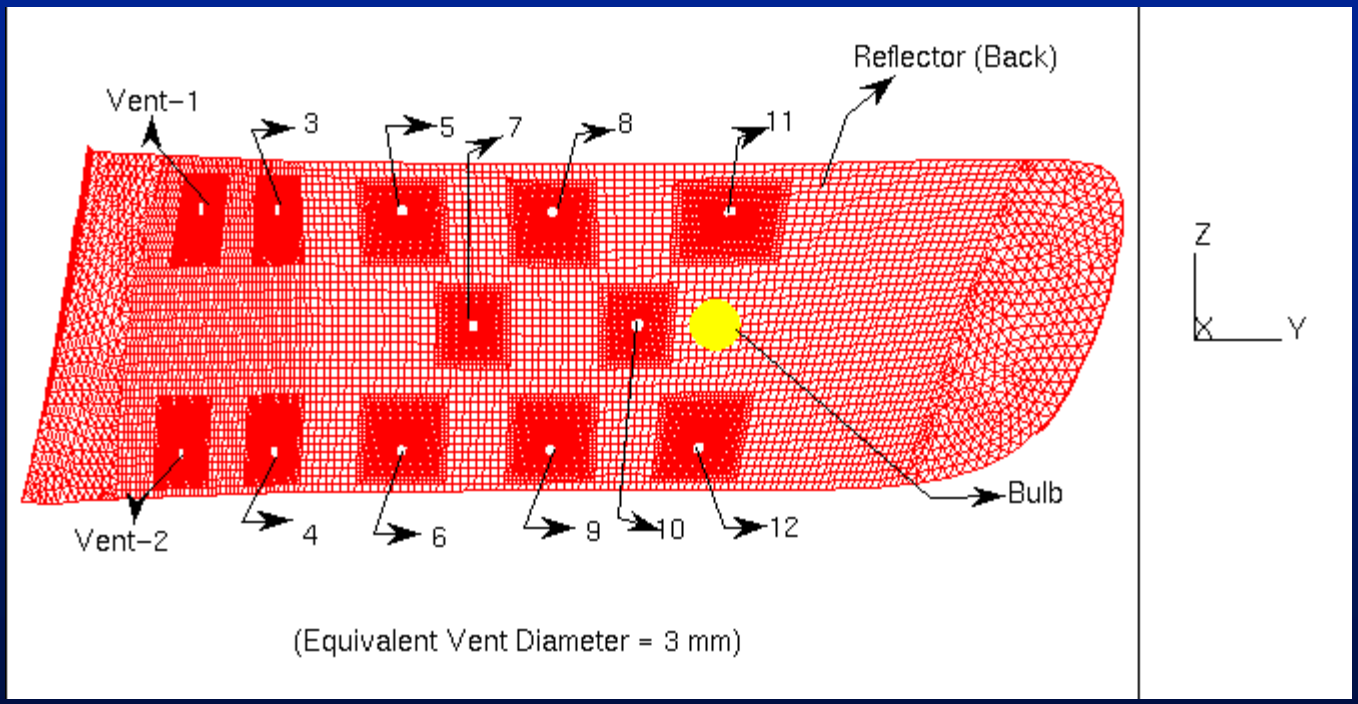
  - designing lamps that would be able to withstand the internal heat generation (by proper material selection)
  - designing lamps that are less susceptible to moisture entrapment and its condensation (by proper design of vents - their numbers, locations, and sizes, etc.)
  - assessing a lamp design from condensation clearing test (a validation test used within GM) standpoint

# Fog Lamp - Model Schematic



# Fog Lamp: Schematic of Vent Locations



# Fog Lamp - Analysis Scope

- To determine the temperature distribution on the walls of the lamp cavity without vents
- To examine the effect of vent (diameter 3 mm) locations on the air exchange rate of the lamp cavity, without and with porous membrane (Gore-tex Patch) on vents
- To examine the effect of vent locations on temperatures and heat transfer coefficients on the walls of the lamp cavity

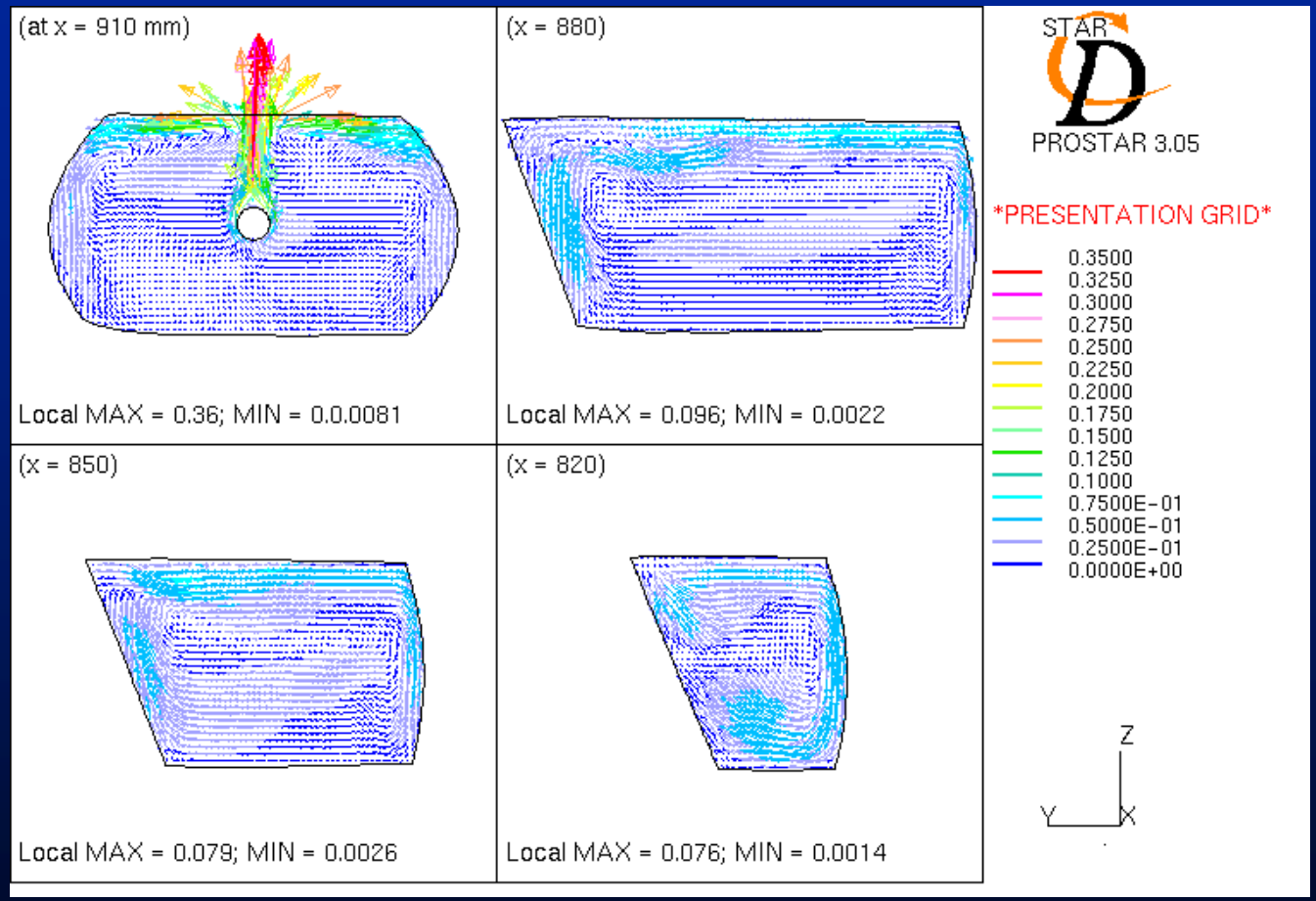
# Fog Lamp - Analysis Overview

- Fluid Flow:
  - Due to buoyancy effects alone
  - Estimated Rayleigh number is of the order of $10^6$. Therefore, the flow regime is laminar.
- Thermal:
  - Conduction (Conjugate Heat Transfer)
  - Natural Convection
  - Radiation
    - Specular radiation (particularly from reflector even though important) is not accounted.
  - The lamp outer surface dissipates heat by radiation and natural convection to the room air temperature. The external surface heat transfer coefficients were estimated using appropriate correlations, depending on the surface orientation.
- Internal details of the bulb are not modeled. Instead, heat flux based on the luminous efficacy and the Wattage of the bulb is imposed on the bulb surface.

# Fog Lamp - Analysis Overview (cont……d)

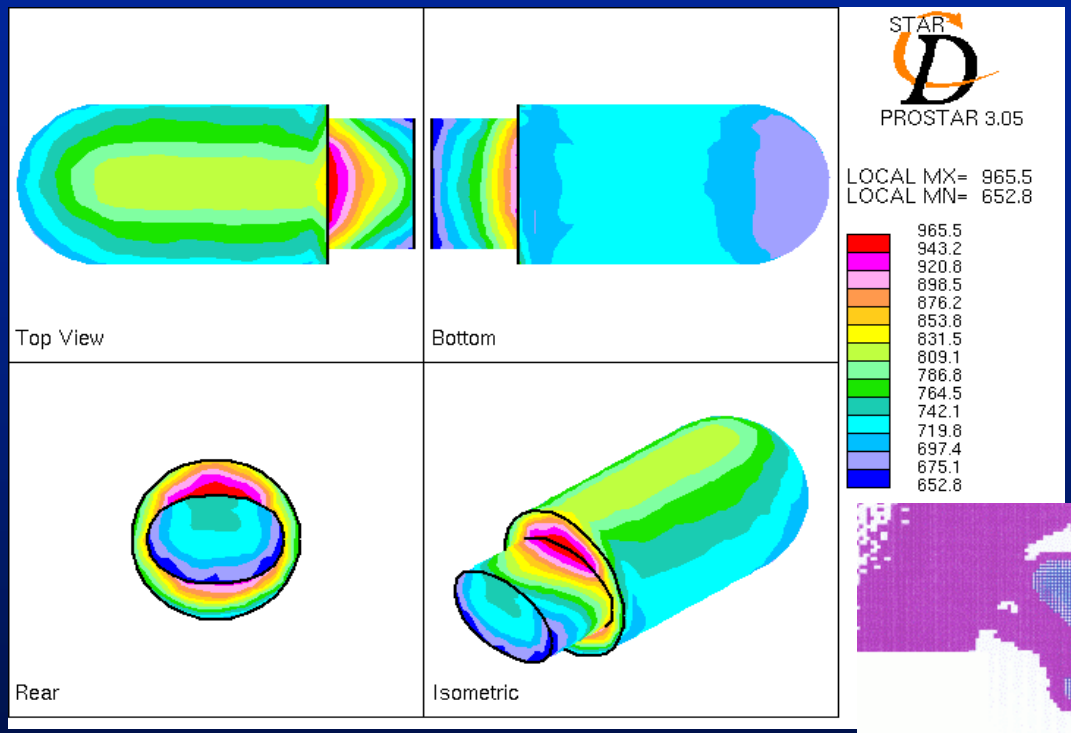
- Constructional details of base, socket, and mounting are not included. Conduction through these paths is assumed to be insignificant.
- Gore-tex patch is modeled as a porous baffle.
- Approximately 300 000 fluid cells
- MARS differencing scheme

# Fog Lamp: Air Velocity Field, m/s



# Fog Lamp: Temperature Distribution

## (Bulb, ° F)

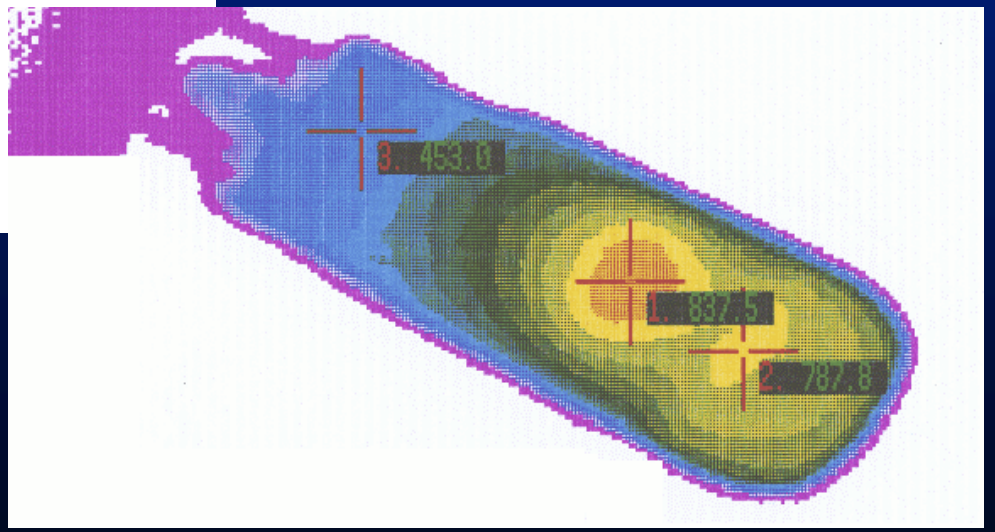






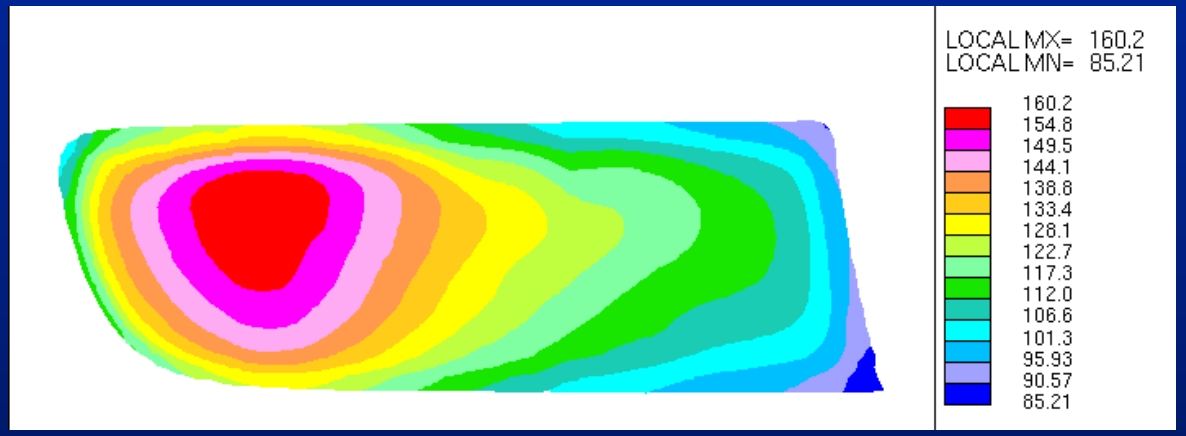
**Computed**

**Measured**



# Fog Lamp: Temperature Distribution

## (Front Lens, ° F)

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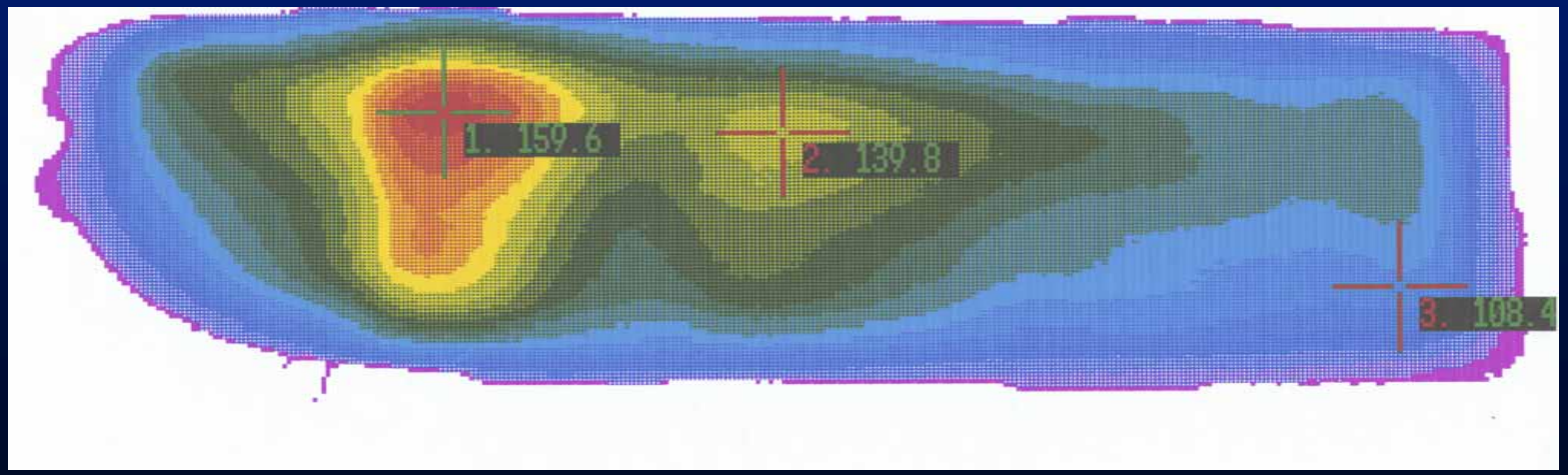
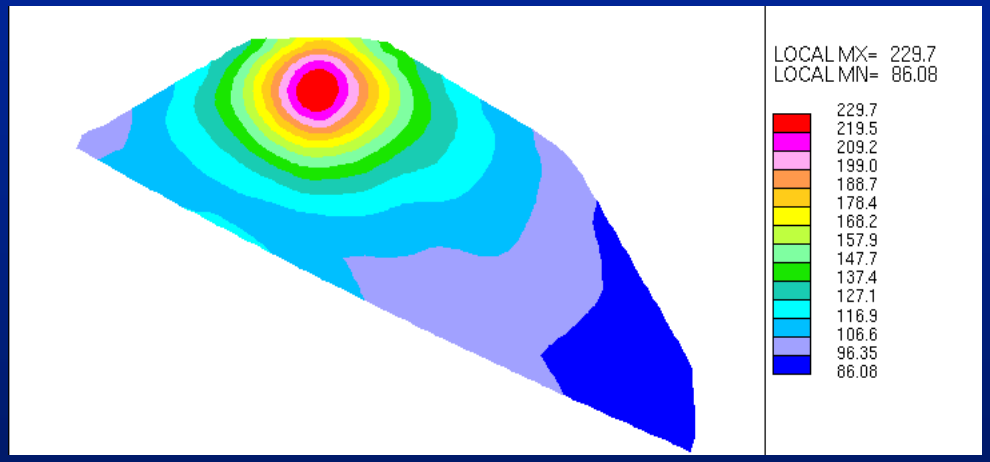



Measured

# Fog Lamp: Temperature Distribution

## (Top Shelf, ° F)

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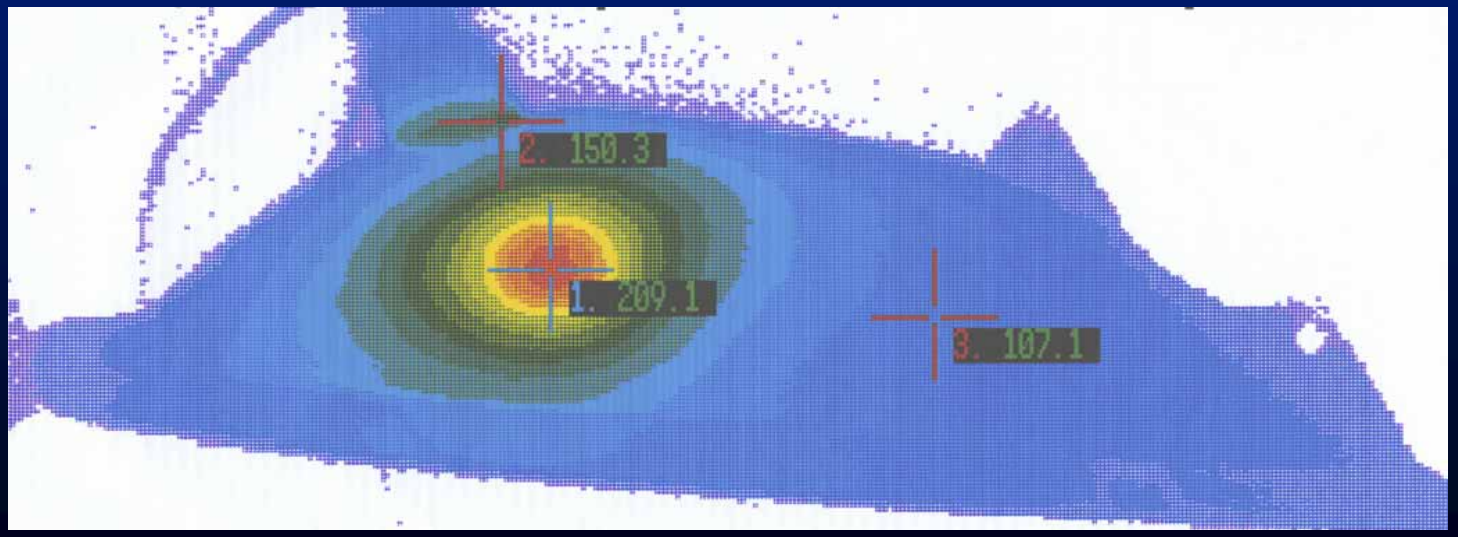
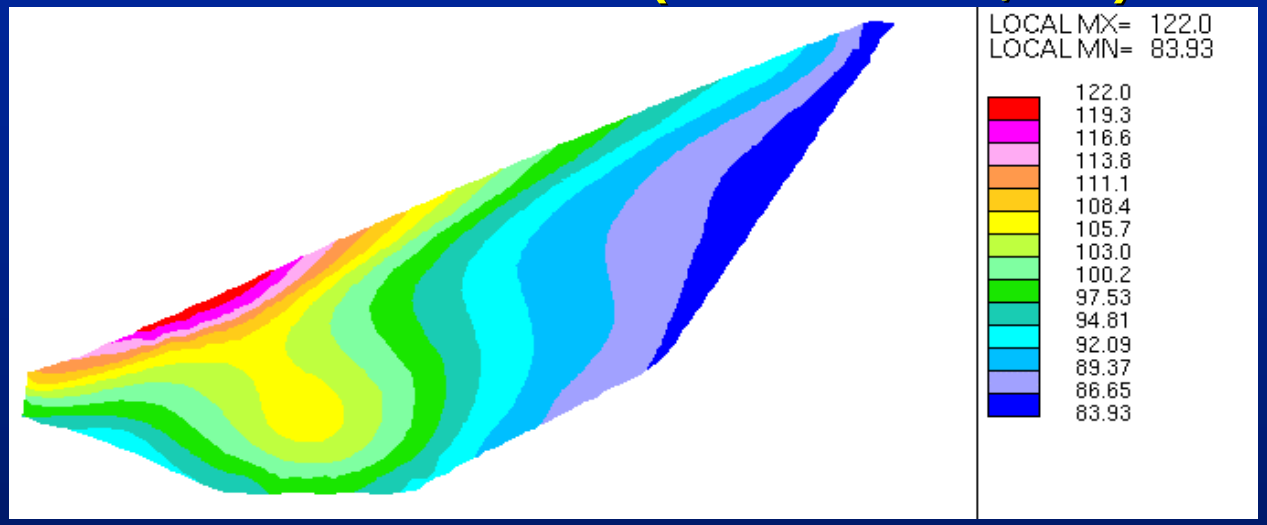



Measured

# Fog Lamp: Temperature Distribution

## (Bottom Shelf, ° F)

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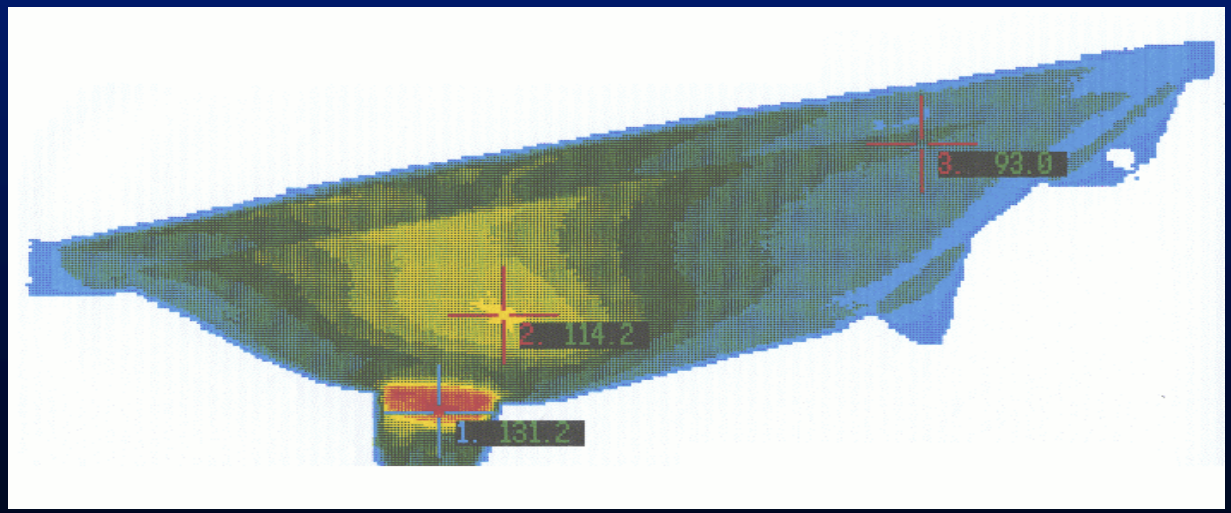
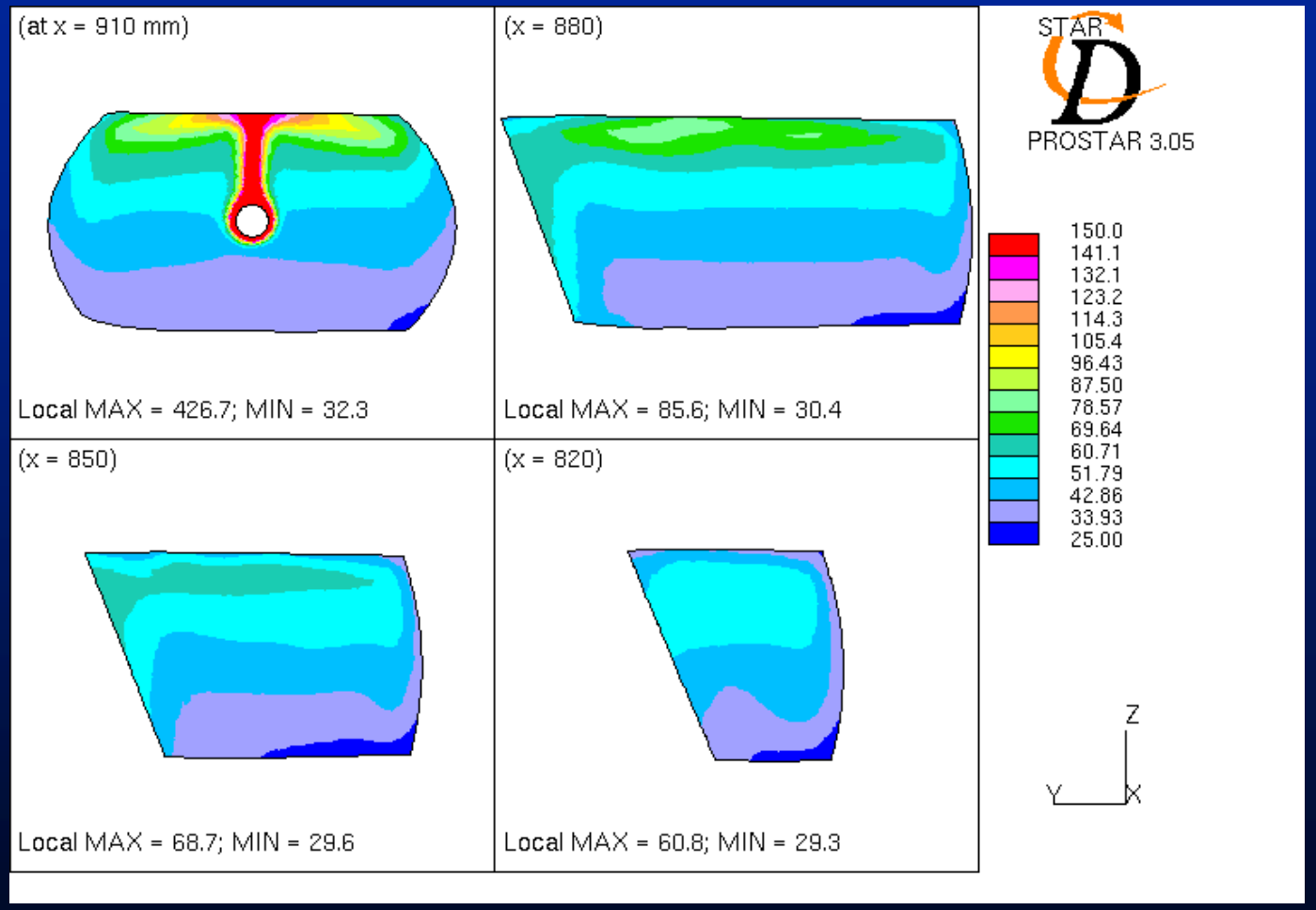
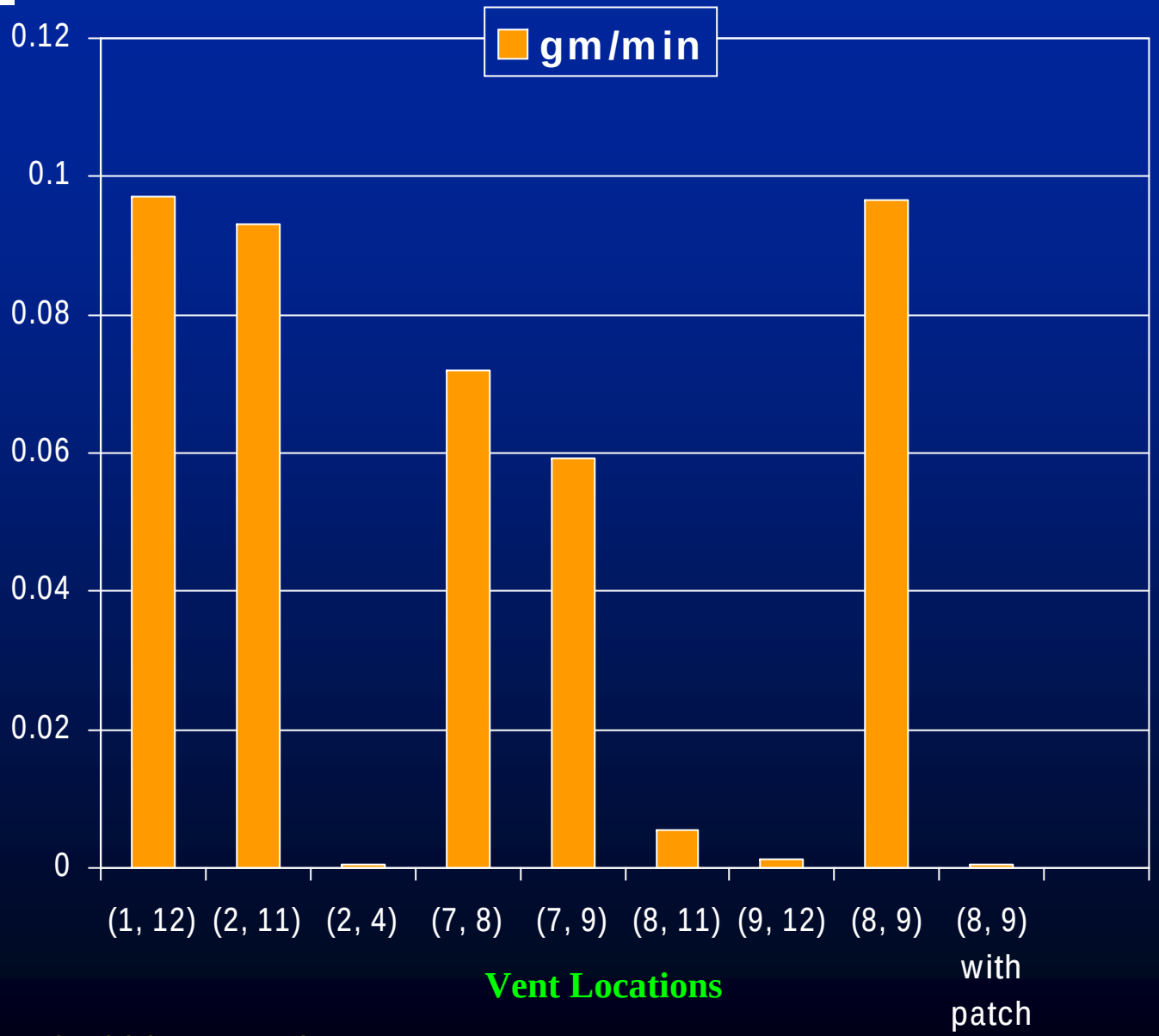



Measured

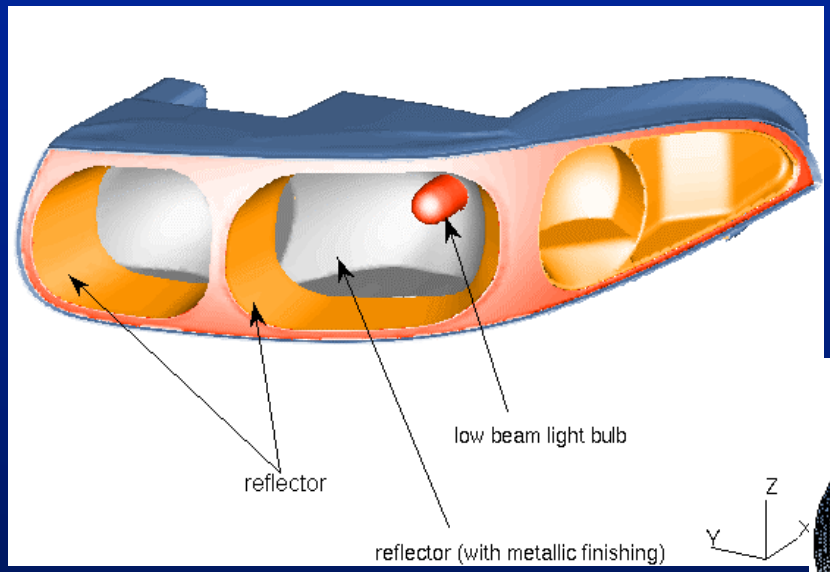
# Fog Lamp: Air Temperature Distribution, ° C

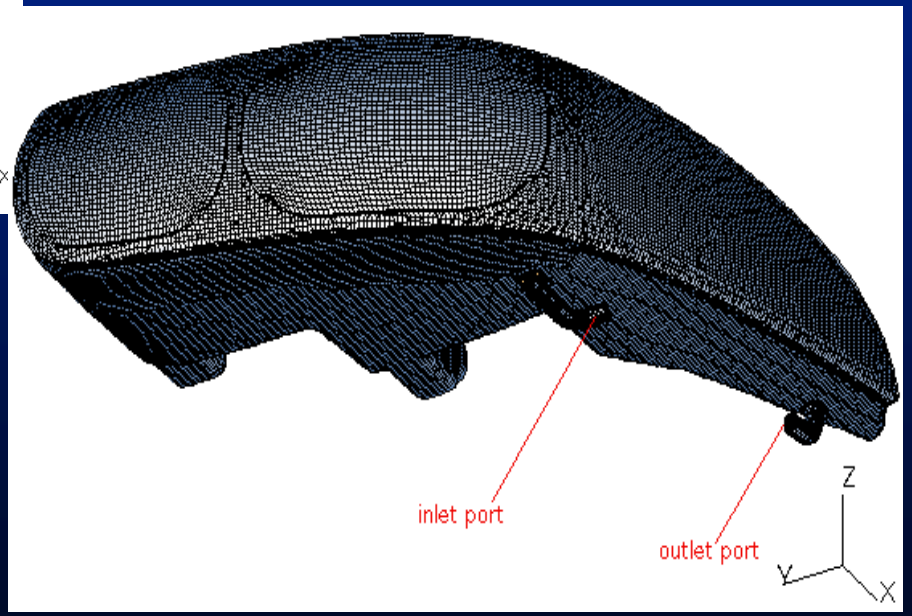


# Fog Lamp: Air Exchange Rate of the Lamp Cavity



# Headlamp - Model Schematic



# Headlamp - Condensation Clearing Test Procedure

- Condensation Formation (Part 1 of the Test):
  - The test vehicle (with lamp in position) is soaked in a hot and humid environment for long enough to reach a constant temperature and humidity levels inside the lamp.
  - Various lamps in the vehicle are then turned on and off for short duration per a specific schedule.
  - Thereafter, the vehicle is moved to the room environment where it is kept for a short while.
  - Consequently, the water vapor trapped inside the lamp condenses on various interior surfaces of the lamp enclosure.
  - This initial condensation pattern is recorded.

## Headlamp - Condensation Clearing Test Procedure (cont….d)

- Condensate Removal (Part 2 of the Test):
  - Following formation of the condensate (at the end of Part 1), the vehicle is driven at a specific speed with low beams on.
  - Condensate clearing pattern is recorded at fixed time intervals for approximately 120 minutes.
- Acceptance Criterion:
  - Condensation must completely clear in X minutes.

# Headlamp - Analysis Scope

- As a first stepping stone towards developing the CFD-based test procedure, this study aims at:
  - predicting the clearing pattern of a given initial distribution of condensate film on the front lens of a headlamp.

# Headlamp - Analysis Overview

- Fluid Flow:
  - Due to the pressure differential across two vents and buoyancy-induced flow resulting from the heat source at the low beam light
- Thermal:
  - Conduction (Conjugate Heat Transfer)
  - Convection (Free and Forced)
  - Radiation
    - Not implicitly incorporated. Instead, heat flux or temperature is assigned on various walls of the lamp enclosure.

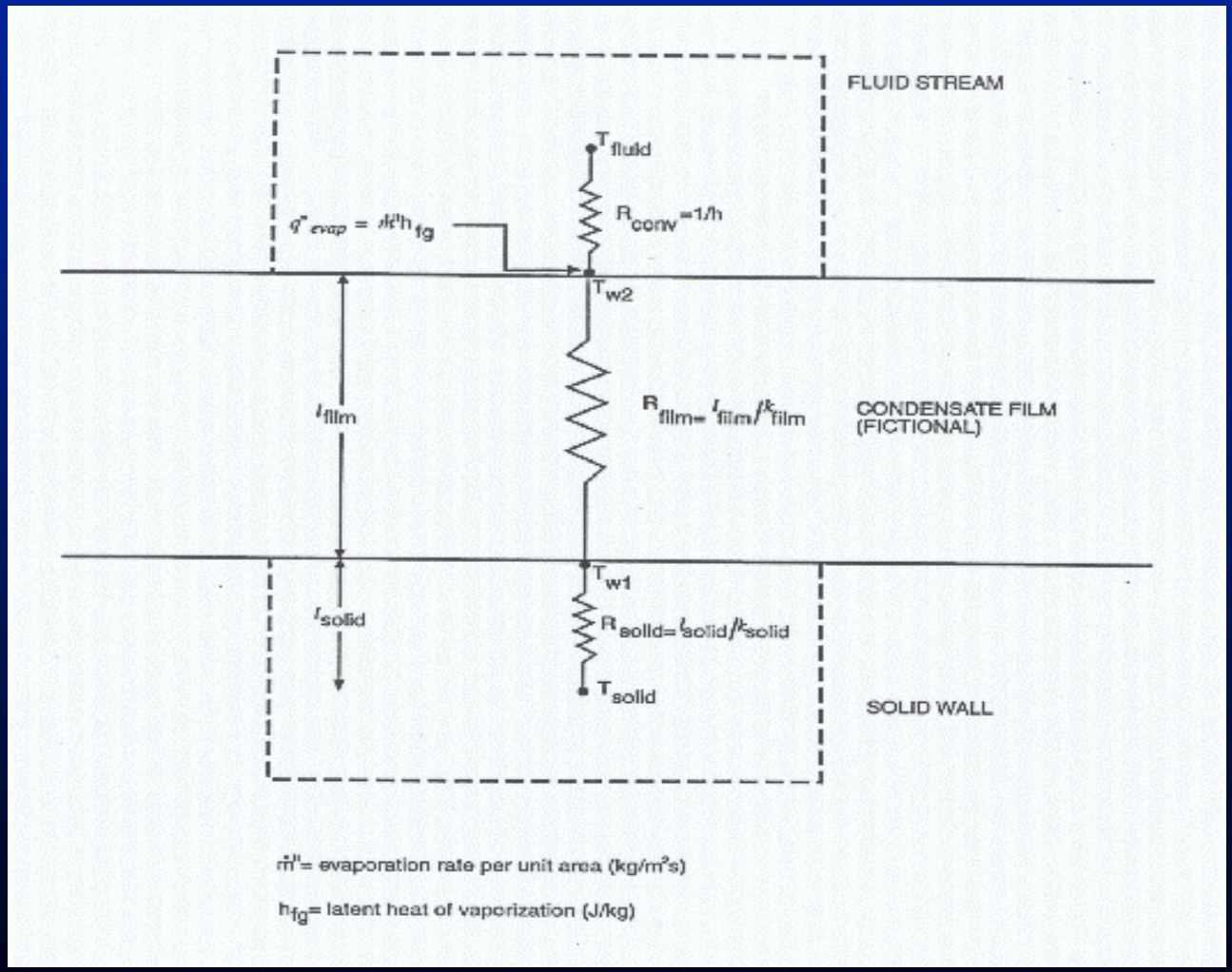
**(Based on an order of magnitude analysis, radiation flux from the bulb, rated at 35 W, impinging on the inner surface of the low beam light chamber is specified.)**

# Headlamp - Analysis Overview (cont…..d)

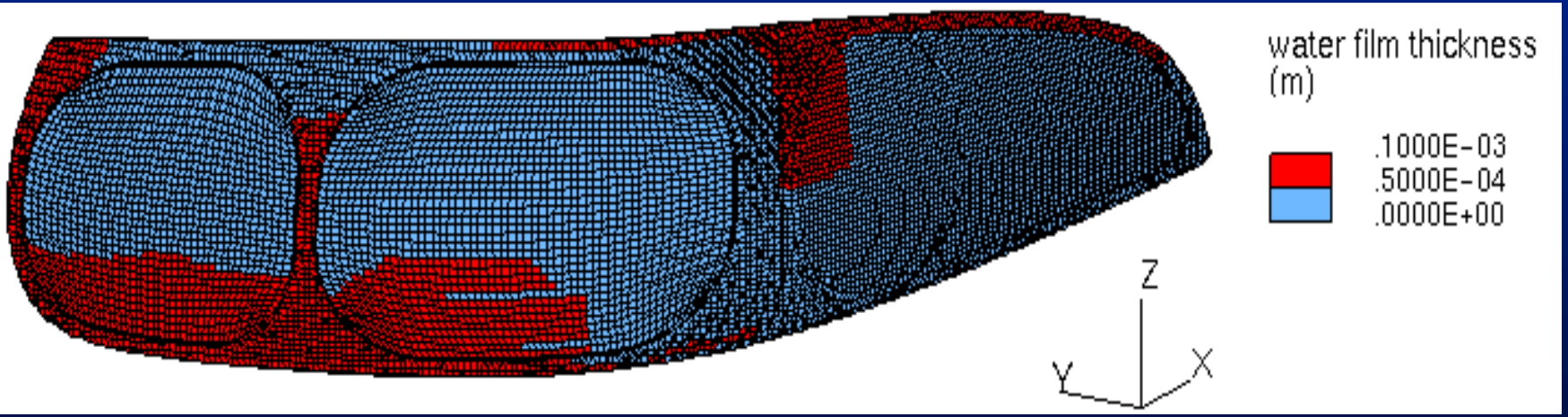
- Water Vapor:
  - Treated as an active scalar quantity in the air/water mixture, meaning that the local thermodynamic properties are determined as function of the local concentration of the water vapor.Therefore, the model invokes the species transport equation.
- Condensation Removal (Evaporation) Model:
  - Evaporation Model - based on the key assumption that the water vapor is in local thermodynamic equilibrium with the condensate film at the phase-change interface.
  - The model is implemented through subroutines *bcdefw.f* and *fluinj.f*
  - Condensation Film - treated as a stationary passive scalar. This allows the tracking of condensate film thickness.

# Headlamp:

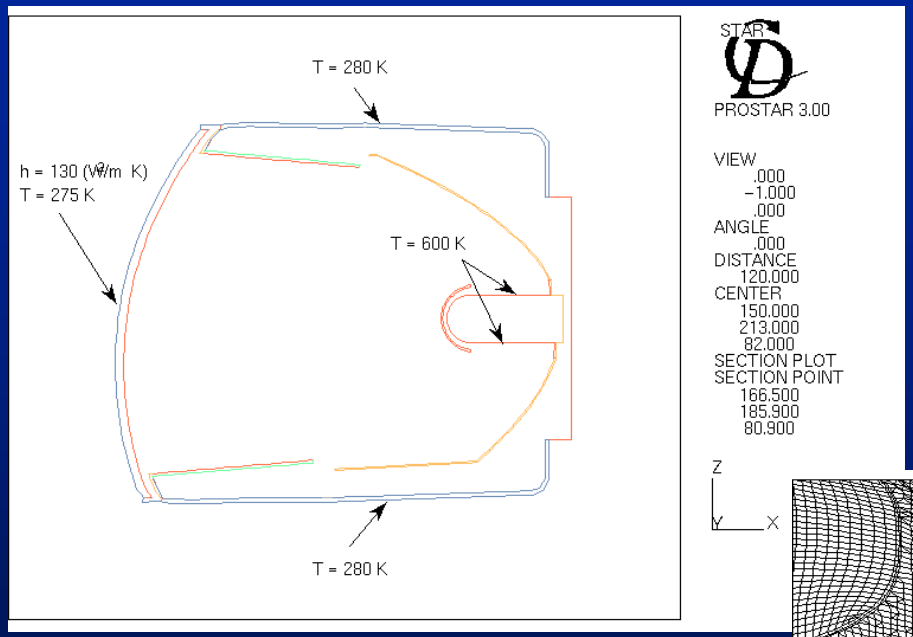
## Thermal Resistance Network for Condensation Removal Model



# Headlamp: Initial Distribution of the Condensation Film on the Lens (Test Data)

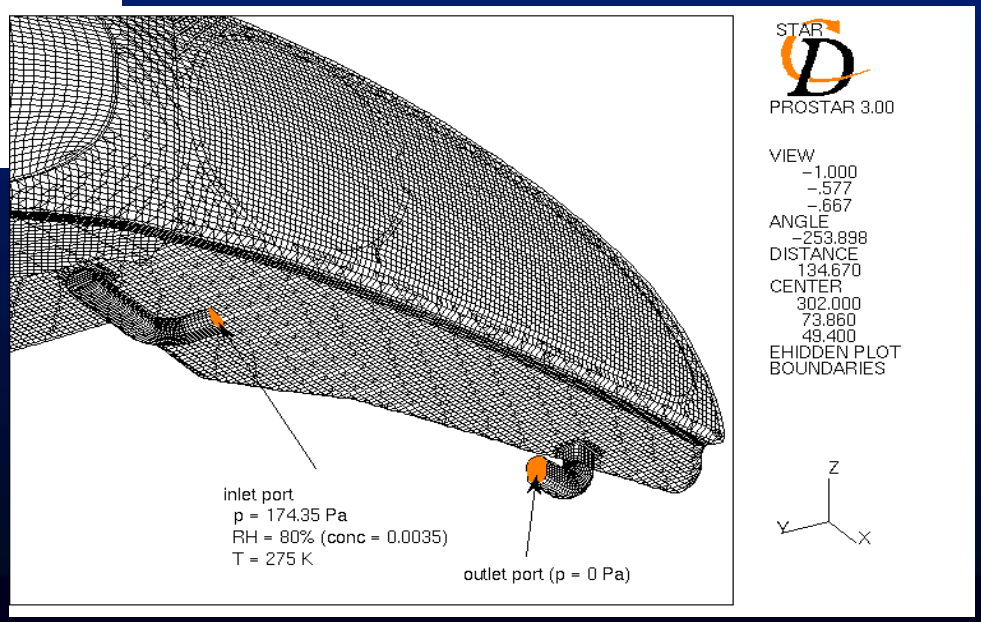


# Headlamp: Boundary Conditions

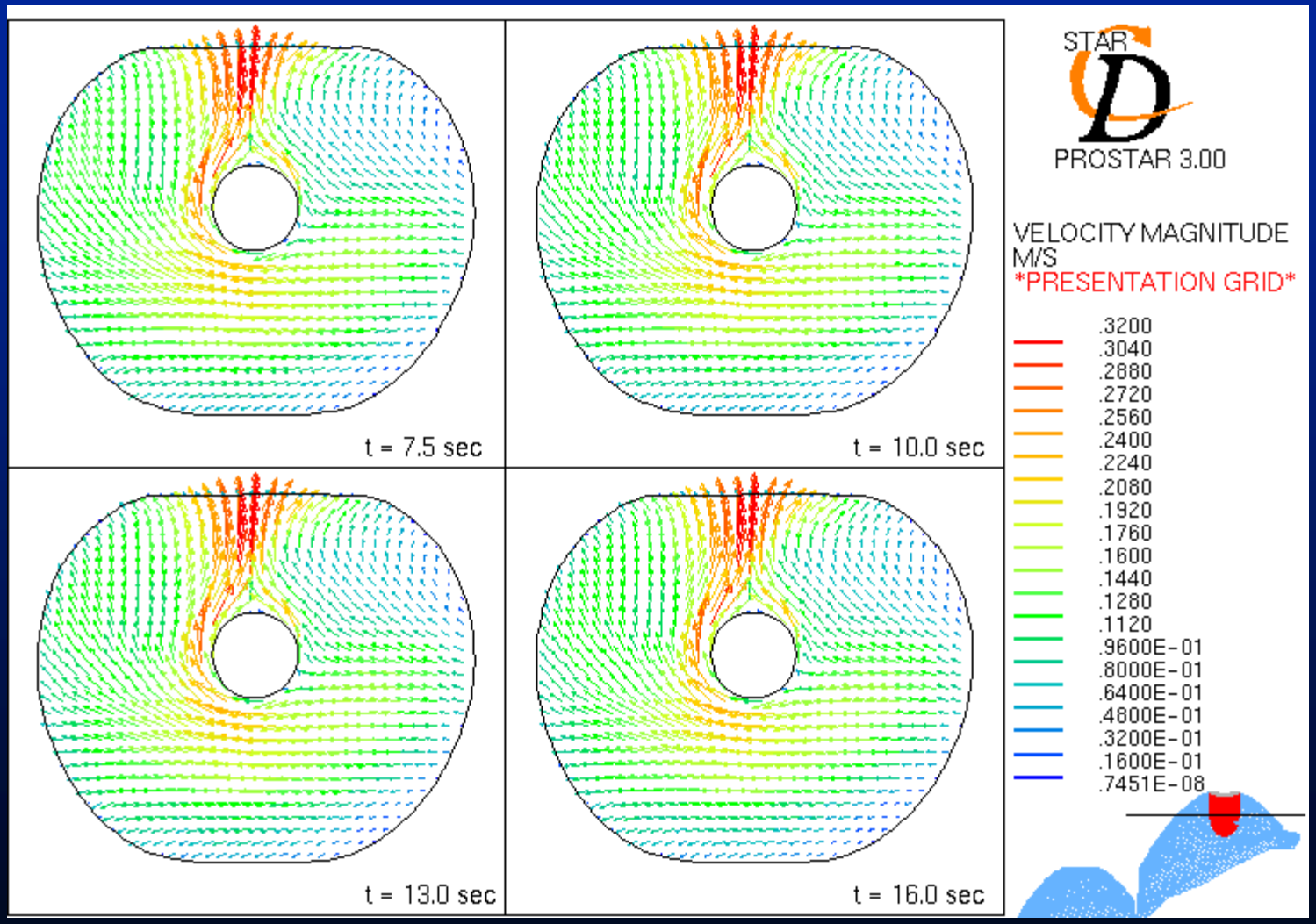








# Headlamp: Velocity Field



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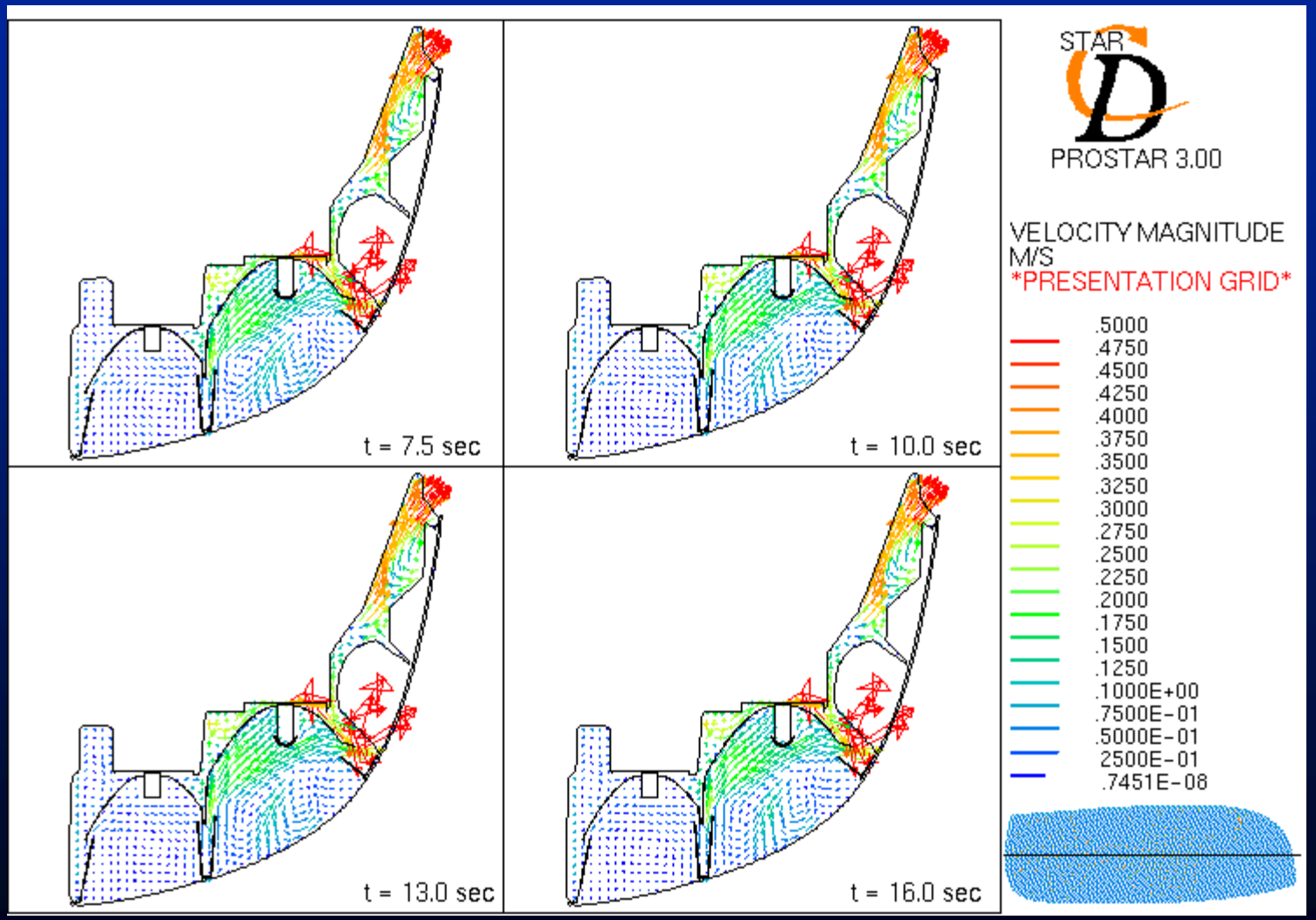
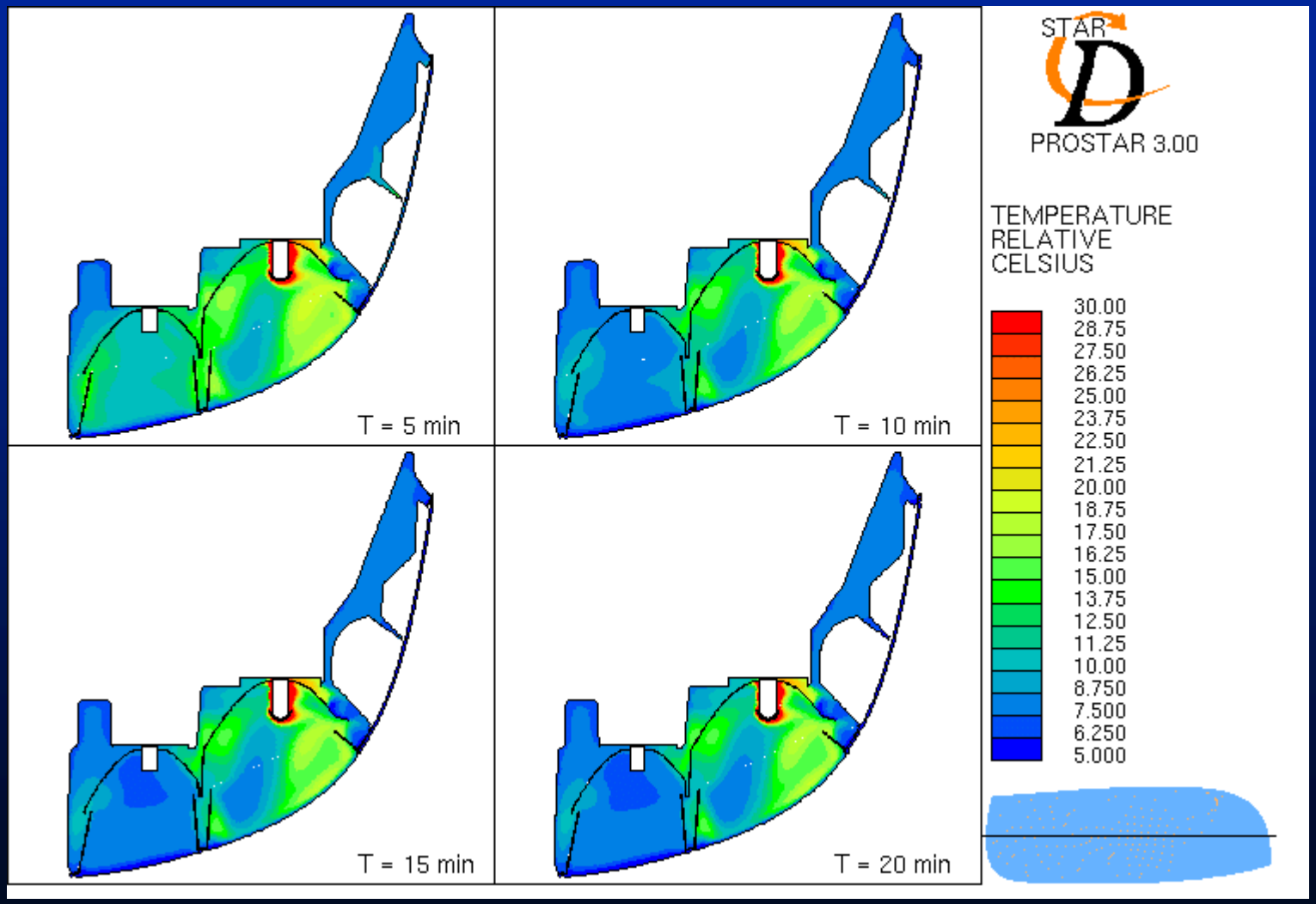
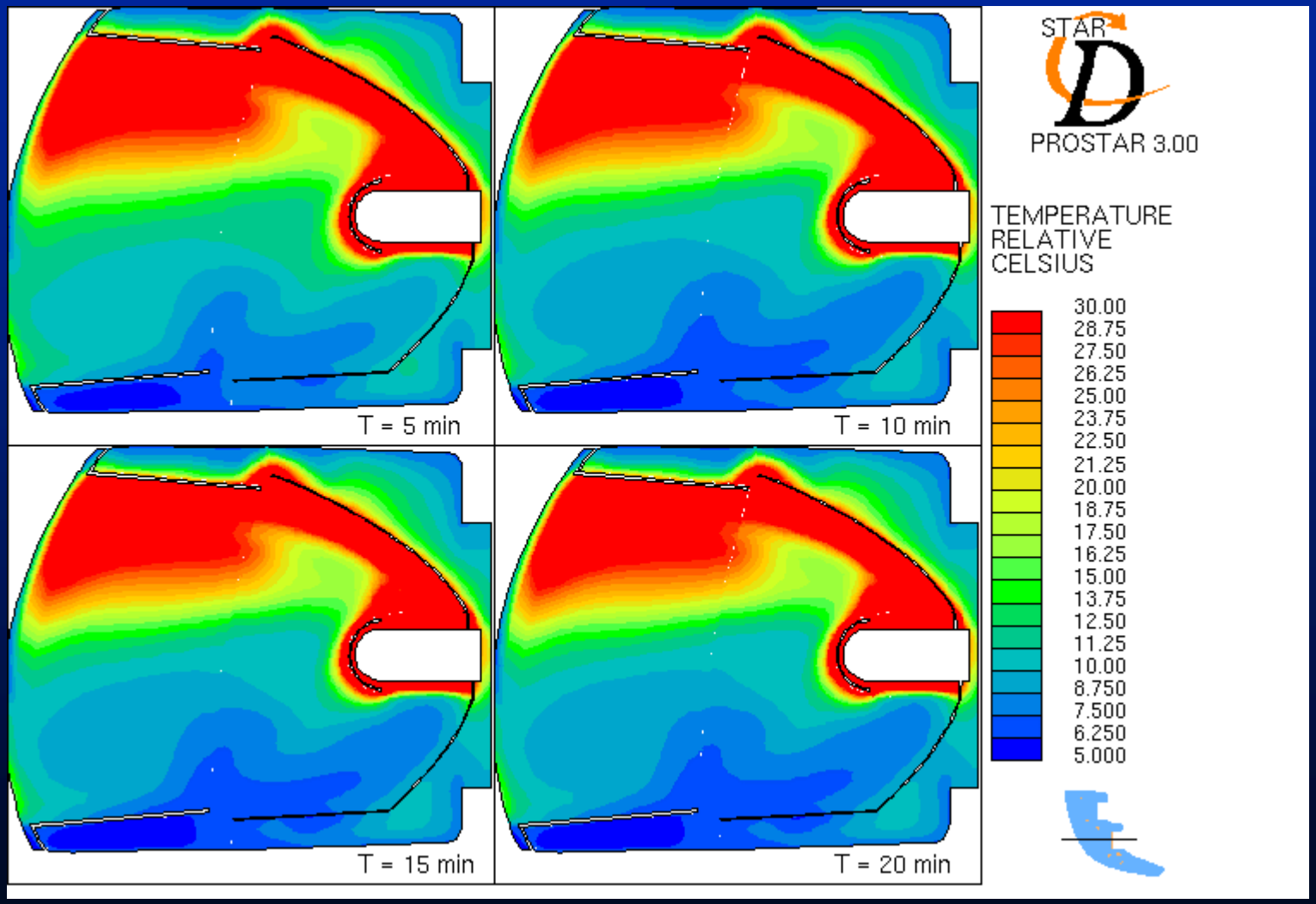


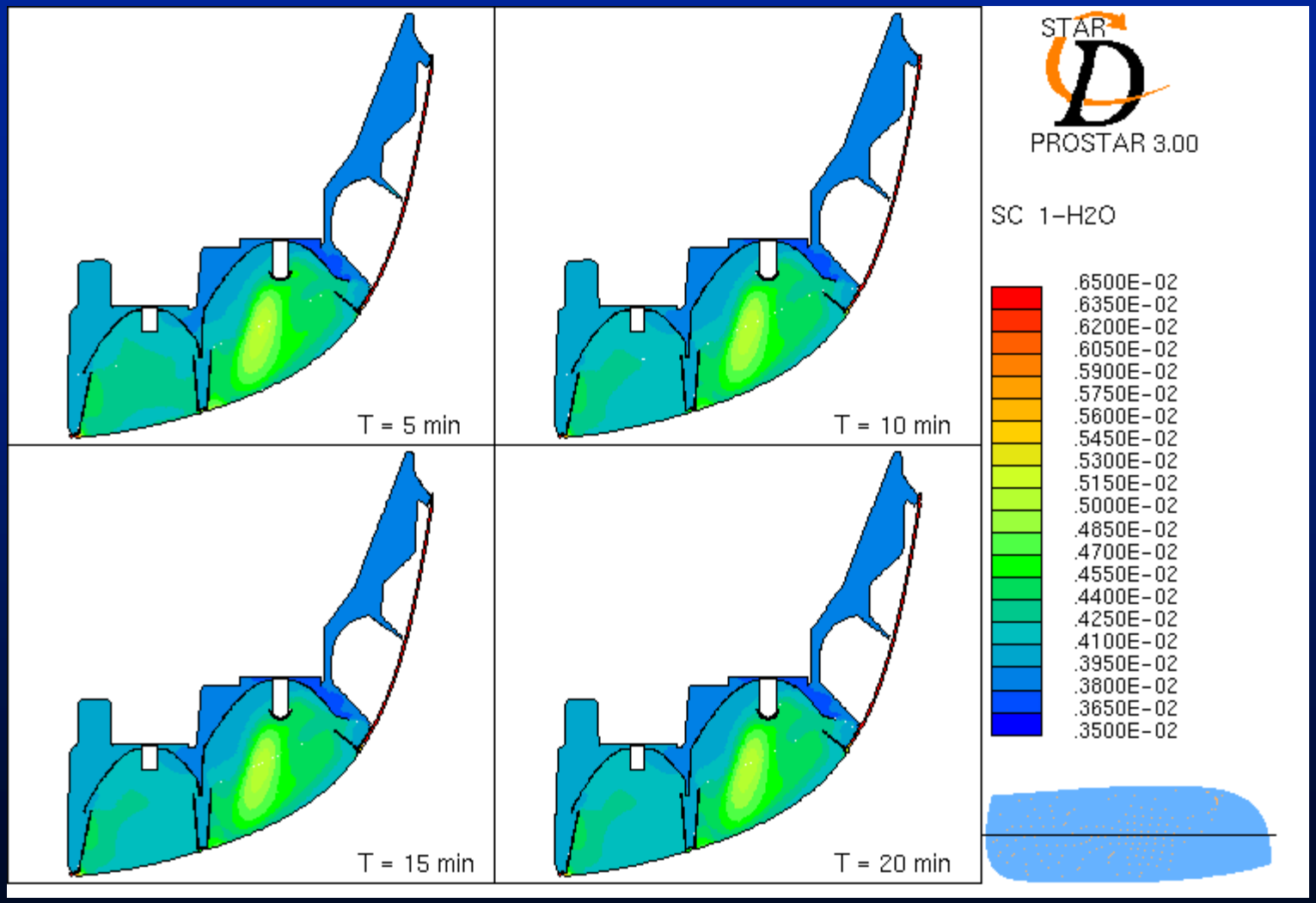
# Headlamp: Temperature Field



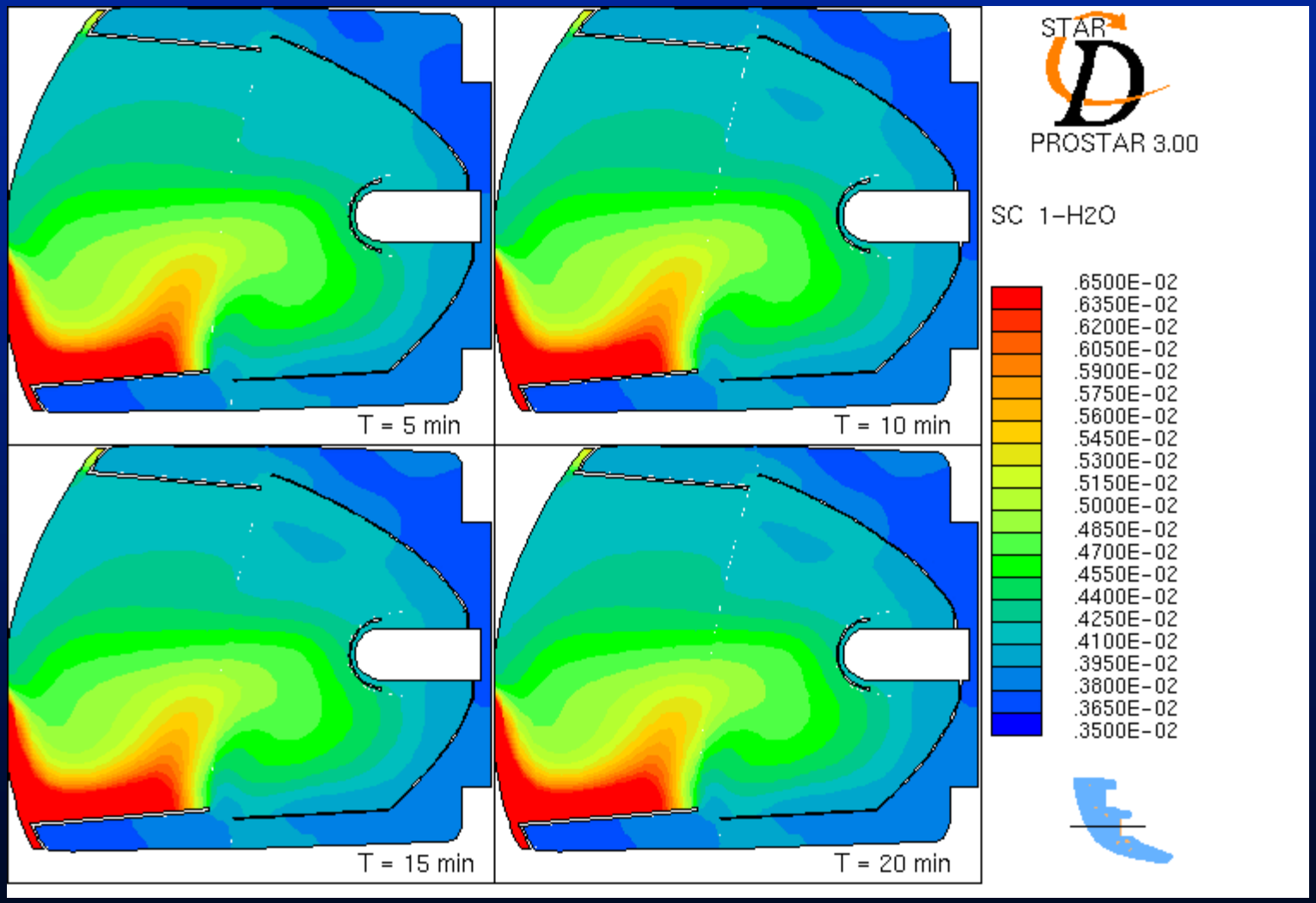
# Headlamp: Temperature Field



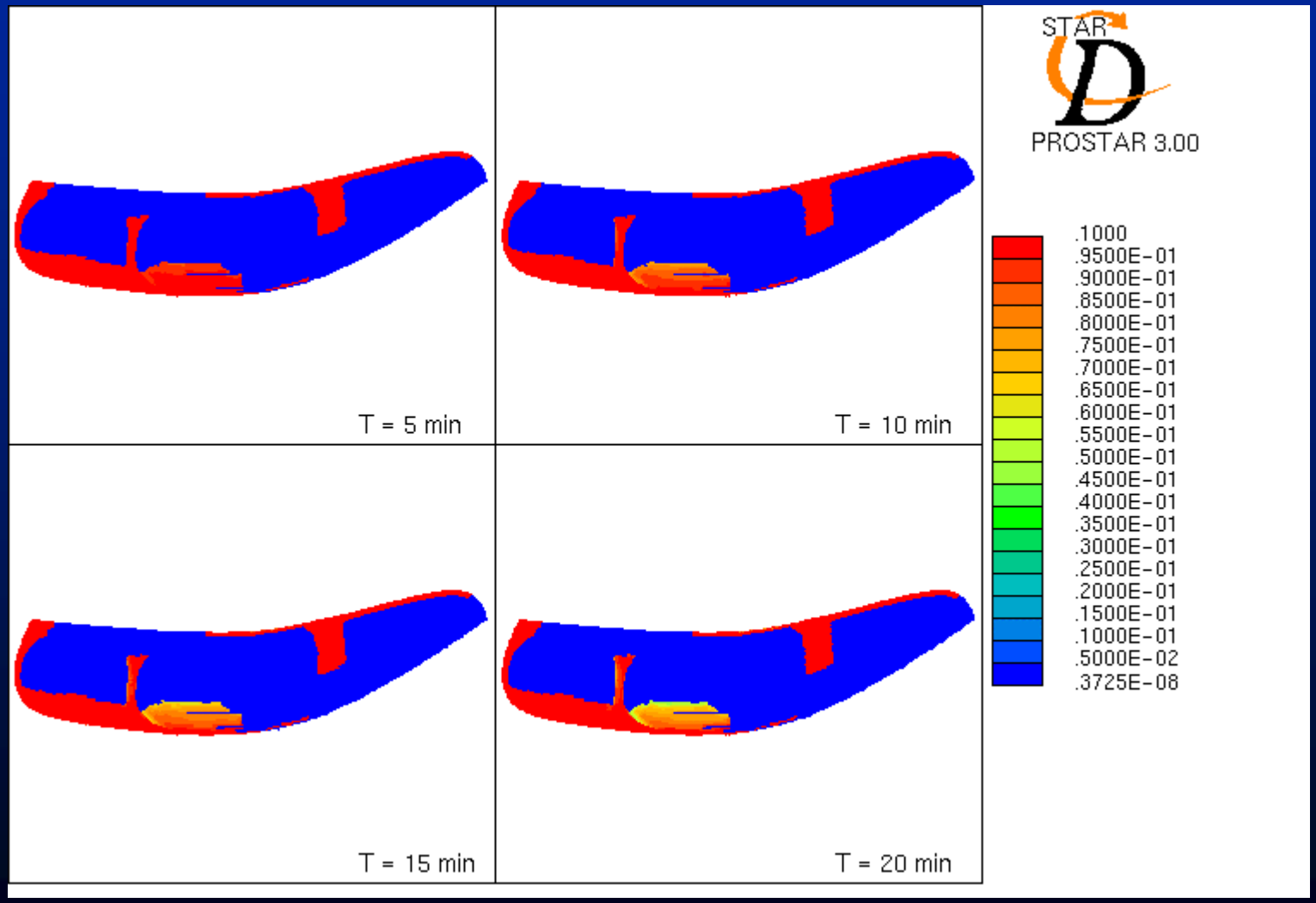
# Headlamp: Vapor Concentration



# Headlamp: Vapor Concentration



# Headlamp:
# Time History of the Condensation Film Thickness, m



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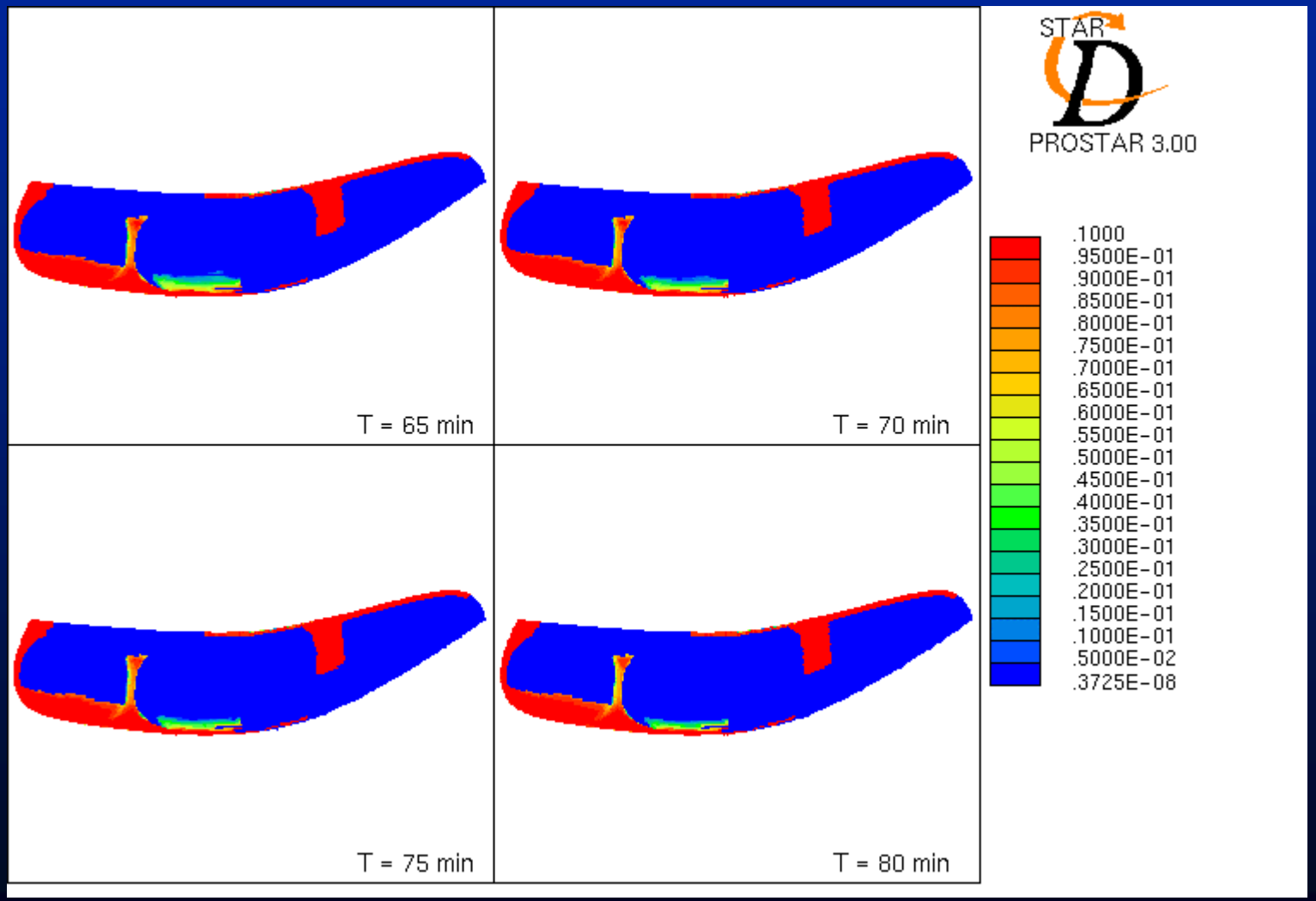

# Closing Remarks

- As a concept, the results obtained from CFD-based models add credence to the analysis.
- Detailed information on airflow pattern and temperature distribution available from analysis models can assist in early identification of problem areas from moisture entrapment and its removal as well as thermal management standpoints.
- Fast A-B comparison featured by different design parameters can be done before prototype is built.

# Closing Remarks (cont……d)

- A self-sustaining simulation process for the condensation clearing test (in purpose to be useful) will require the modeling of condensation phenomenon.
- For better accuracy and predictive capability, incorporation of appropriate radiation models (including specular radiation) in STAR is required.
- As analysis procedures improve and become more robust, greater benefits of using the CFD-based models can be attained in engineering of various automotive lamps.