Critical Design Review
JSC-Houston, 13-16 May 2003

AMS Tracker Thermal Control System
(TTCS)

CDR Data Package

Bart Verlaat (NIKHEF)
Ad Delil, Aswin Pauw, Gerrit van Donk & Arend Woering (NLR)
The AMS-2 Silicon Tracker

Radiators for the Tracker (2x1.25 m²)

192 Hybrids producing each 0.75 Watt of heat (144 W total)

The AMS-2 Silicon Tracker
CDR Data Package

Tracker Thermal Control System

TTCS

Thermal bar connection to permanent magnet (Will be the interface to the TTCS in AMS-02)

Silicon Ladders

Heat producing hybrids

Tracker carbon fiber support structure

Photo of the AMS-1 Silicon Tracker
AMS-Silicon Tracker
Thermal Requirements

Silicon wafer thermal requirements:
- Operating temperature: -10 °C / +25 °C
- Survival temperature: -20 °C / +40 °C
- Temperature stability: 3 °C per orbit
- Maximum accepted gradient between any silicon: 10.0 °C
- Dissipated heat: 2.0 Watt EOL

Hybrid circuit thermal requirements:
- Operating temperature: -10 °C / +40 °C
- Survival temperature: -20 °C / +60 °C
- Dissipated heat: 144 W total (±10%), 0.75 W per hybrid pair (S=0.47 W, K=0.28 W)

Star Tracker thermal requirements:
- Operating temperature: -30 °C / 40 °C
- Survival temperature: -40 °C / 100 °C
- Dissipated heat: 6.8 W total, 3.4 W per ASTS
AMS-Tracker Thermal Control System (TTCS)
(A mechanically pumped CO$_2$-Loop)

- The Tracker Thermal Control System (TTCS) is a system to control the temperature of the AMS-Tracker within a 10 °C gradient inside the Tracker and an over orbit stability better than 3 °C.
- The system uses carbon dioxide (CO$_2$/R744) as working fluid. The 144 Watt heat dissipation inside the Tracker is absorbed by the CO$_2$ using the latent heat of evaporation.
- The fluid is being circulated using a centrifugal pump.
- The evaporator temperature is maintained constant over orbit by a peltier controlled accumulator vessel. The evaporator temperature can be set between −15 °C and +15 °C.
- The total heat (Tracker + TTCS) is rejected to space by 2 opposite facing radiators (ram and wake). The radiators are out of phase to damp the incoming orbital flux excursions to a minimum.
- The TTCS will also take care of the thermal control of the Amiga Star Tracker System.
Secondary TTCS (TTCSS)

- Ram Heat Pipe Radiator
- Wake Heat Pipe Radiator
- Top Evaporator
- Bottom Evaporator
- Tracker Hybrids
- Pre heater
- Heat Exchanger
- Pumps
- Phase Change Material (PCM)
- Accumulator
- Zones heaters (CGS)
- Wake Condenser
- Pre heater
- 2-Way Valve (VLV)
- Centrifugal pump (PMP) with integrated check valve
- Electrical Heater (HTR)
- Sensors:
  - LFM = Liquid Flow Meter
  - DPS = Differential Pressure Sensor
  - APS = Absolute Pressure Sensor
  - VQS = Vapor Quality Sensor

Components inside this profile are thermally mounted to the TTCB structure.

Thermo Electric Cooler (TEC)
TTCS Evaporator

- **Top evaporator loops**
- **Outer plane thermal bars**
- **Inner plane thermal bars**
- **Bottom evaporator loops**
**TTCS Condenser**

- **Inlet & Outlet**
- **Header lines and support**
- **Stainless steel vapor lines (Orange)**
- **Condenser section (Aluminum heat pipe channels)**
- **Stainless steel Liquid lines (Cyan)**

**TTCS**

Tracker Thermal Control System

CDR Data Package
TTCS Radiator

- Embedded heat pipe radiator panel
- Carbon fiber support struts
- TTCS CO₂ Condensers
TTCS Control Hardware Location

- TTPD Power Distribution Box
- TTCE Control Electronics Box
- Primary TTCS Component box
- Secondary TTCS Component Box
TTCSP Component Box

- Peltier elements
- Accumulator
- Pre-heater sections
- Experiment valves
- USS lower trunnion bridge
- TTCB base plate
- Pumps
- Pump control valves
- Heat exchanger
- TTCB envelope
- Radiator control valves
- Evaporator / Condenser connections
Pacific Design Technologies (PDT) in Goleta (Ca) has been contracted to develop the TTCS pumps.

The TTCS pump will be a modified Mars Pathfinder centrifugal pump, optimized for the TTCS flow- and differential- and system pressure range, but with the reliability of the proven Pathfinder pump, which has operated successfully during the mission to Mars.
Primary TTCS (TTCSP)

Components inside this profile are thermally mounted to the TTCB structure

Thermo Electric Cooler (TEC)
**TTCSP Overview**

- **All thermal experiment hardware in the TTCSP.**
- **Valves to create experimental cases and thermal control cases**
- **Different evaporator concepts possible owing to valves.**
  - Parallel operated evaporators
  - 1 pump per evaporator
  - Serial operated evaporators
  - Evaporator by-pass for thermal experiments
- **Condenser optimization**
  - Too cold or too warm condensers can be closed or restricted by valves
- **Valves are redundant such that in case of a single failure the TTCSP is still functioning at a level better than the secondary TTCS (Which has no actuators other than the pumps). Only experimental or optimization cases are affected.**
- **A PCM (Phase Change Material) is foreseen to damp the orbital load. (Hot solar peak buffering)**
**TTCSP Component overview**

**Inside TTCBP**
- 2x Pump (PDT Model 5059-1; 2-Stage centrifugal pump with integrated check valves)
- 10x Proportional two-way valves (Bradford Engineering)
- 1x Accumulator (1.3 Liter), (Self engineered)
- 1x Phase change material (A melting/freezing paraffin buffer, Supplier Esli)
- 1x Three volume heat-exchanger (Self engineered)
- 2x Peltier elements (Supplier: Melcor)
- 3x Liquid flow meter (Via Differential pressure using Keller DPS sensors)
- 2x Absolute pressure sensor (Supplier: Keller)
- 1x Differential pressure sensor (Supplier: Keller)
- TBDx Dallas temperature sensors (Dallas DS18S20/TO92)
- TBDx PT100(0) temperature sensors (Supplier TBD)
- 10x Electrical shielded resistance wire heaters (Supplier: Thermacoax)

**Outside TTCBP**
- 2x Evaporator assemblies (Self engineered)
  (Evaporator is qua design the only common shared hardware between the primary and the secondary TTCS)
- 2x Condenser (Self engineered)
- Thermal control electronics in TTCE crate on wake radiator (Self engineered)
**TTCSS Overview** (Schematic layout is shown on page 6)

- **No experimental hardware in the TTCSS.**
- **No actuated valves**
- **1 evaporator concept possible:**
  - Parallel operated evaporators only
- **No Condenser optimization possible.**
- **Due to the absence of control valves the secondary TTCS will show a worse thermal performance than the primary. (More pre-heat power)**
- **The secondary is simpler (No active components other than the pumps) thus more reliable than the primary TTCS.**
- **No sensors (other than the APS) are in the pressurized volume.**
- **A PCM (Phase Change Material) is foreseen to dampen the orbital load (Hot solar peak buffering).**
TTCS Component Overview

Inside TTCBS:
• 2x Pump (PDT Model 5059-1; 2-Stage centrifugal pump with integrated check valves)
• 1x Accumulator (1.3 Liter), (Self engineered)
• 1x Phase change material (A melting/freezing paraffin buffer, Supplier Esli)
• 1x Three volume heat-exchanger (Self engineered)
• 2x Peltier elements (Supplier: Melcor)
• 2x Absolute pressure sensor (Supplier: Keller)
• TBDx Dallas temperature sensors (Dallas DS18S20/TO92)
• TBDx PT100(0) temperature sensors (Supplier TBD)
• 10x Electrical shielded resistance wire heaters (Supplier: Thermacoax)

Outside TTCBS:
• 2x Evaporator assemblies (Self engineered)
  (Evaporator is qua design the only common shared hardware between the primary and the secondary TTCS)
• 2x Condenser (Self engineered)
• Thermal control electronics in TTCE crate on wake radiator (Self engineered)
TTCS Main material and construction overview

General materials

• Tubes: CRES 316L
• Evaporator bridges: OFHC Copper
• Condenser profiles: AA 6061
• Refrigerant: CO₂ (R744)
• Bolts: CRES A286 (#10 and above) and CRES 316 (up to M4)
• Thermal spacers: G10 and Teflon
• Support brackets: AA 6061
• Insulation: MLI

General construction

• Pressurized volume is an all welded sealed system. Weld types included are:
  – Gas Tungsten Arc Welding (Orbital welding)
  – Laser welding
  – Inertia welding (Aluminum to stainless steel)
• No connectors are foreseen, but may be introduced later due to assembly constrains. (Candidate connector supplier: Dynatube)
• Thermal interface connection of copper heat sinks to stainless steel tubes by soft soldering with Sn96Ag filler.
• Glued interfaces using AV138m/HV998 glue (Thermal joints, non structural)
• Use of NASA provided bolts from #10. (Use of self provided metric bolts up to M4)
TTCS Thermal Requirements

TTCB (Component box) thermal requirements:
- Operating temperature: -50 °C / +25 °C
- Survival temperature: -50 °C / +80 °C
- Allocated power: 70 Watt

TTCE (Control electronics) thermal requirements:
- Operating temperature: -20 °C / +55 °C
- Survival temperature: -40 °C / +80 °C
- Allocated power: 3.5 Watt

Evaporator thermal requirements:
- Operating temperature: -20 °C / +25 °C
- Survival temperature: -40 °C / +80 °C

Condenser thermal requirements:
- Operating temperature: -50 °C / +25 °C
- Survival temperature: -100 °C / +80 °C
TTCS Structural Requirements
(Applicable documents)

- **Pressurized components designed and tested according to:**
  MIL-STD-1522A,
  *(Standard General Requirements For Safe Design And Operation Of Pressurized Missile And Space Systems)*

- **Pressurized welds are manufactured and tested according to:**
  PRC-0010, Rev. A., class B.
  *(Process Specification for Automatic and Machine Arc Welding of Steel and Nickel Alloy Flight Hardware)*

- **Non Pressurized hardware is designed according to:**
  JSC-20545 Rev A.
  *(Simplified Design Options for STS-Payloads)*
Other TTCS design criteria:

- Maximum Design Pressure (MDP): 160 bar (@ 80°C)
- TTCS Volume per system: 1.9 Liter
- Accumulator Volume: 1.3 Liter
- TTCS CO₂ filling per system: 874 gram
- Allowed system leak rate: 1*10⁻⁶ mbar*l/s
- Mission duration: 5 Years
TTCS verification (1/2)

Performance testing:
- Under normal atmospheric conditions (Insulated):
  - Full scale development breadboard model
  - Flight hardware system testing using a cold plate (Radiator removed)

Thermal Vacuum tests:
- Thermal cycling
  - on all relevant subsystems and components for qualification
- Thermal balance and thermal vacuum performance tests
  - on subsystem level when necessary for system performance, e.g.:
    - Thermal Bars,
    - TTCS Box
- Complete system level test of the TTCS during AMS-02 overall thermal vacuum testing.
**TTCS verification (2/2)**

**EMC/EMI:**
- Electromagnetic compatibility/interference testing on all relevant subsystems

**Structural testing:**
- Proof pressure on flight hardware (Components, TTCS assembly)
- Burst pressure tests using non-flight hardware (On components only)
- Leak testing:
  - Helium leak tests on flight components
  - Pressure decay test on the complete TTCS after proof pressure testing
- Vibration testing:
  - Thermal bars (Prototype hardware)
  - TTCB (Component box)
  - TTCE (Electronics crate)
TTCS Thermal Modeling

Thermal model of detector with conductors represented as links (I-DEAS, NIKHEF)

Model exchange

Cooling system modeling with fluid properties (SINDA/Fluint, NLR/Noordoostpolder)

Model exchange

Cooling system set point

Orbital fluxes boundary conditions

Cooling system set point and power dissipation

Complete AMS thermal model on International Space Station model to calculate orbital fluxes. (SINDA, CGS/Milan)