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Active Thermal Control System Evolution

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Abstract

The "restructured" baseline of the Space Station Freedom (SSF) has eliminated many of the growth options for the Active Thermal Control System (ATCS). Modular addition of baseline technology to increase heat rejection will be extremely difficult. The system design and the available real estate no longer accommodate this type of growth.

As the station matures during its thirty years of operation, a demand of up to 165 kW of heat rejection can be expected. The baseline configuration will be able to provide 82.5 kW at Eight Manned Crew Capability (EMCC). The growth paths necessary to reach 165 kW have been identified.

Doubling the heat rejection capability of SSF will require either the modification of existing radiator wings or the attachment of growth structure to the baseline truss for growth radiator wing placement. Radiator performance can be improved by enlarging the surface area or by boosting the operating temperature with a heat pump. The optimal solution will require both modifications. The addition of growth structure would permit the addition of a parallel ATCS using baseline technology. This growth system would simplify integration. The feasibility of incorporating these growth options to improve the heat rejection capacity of SSF is under evaluation.

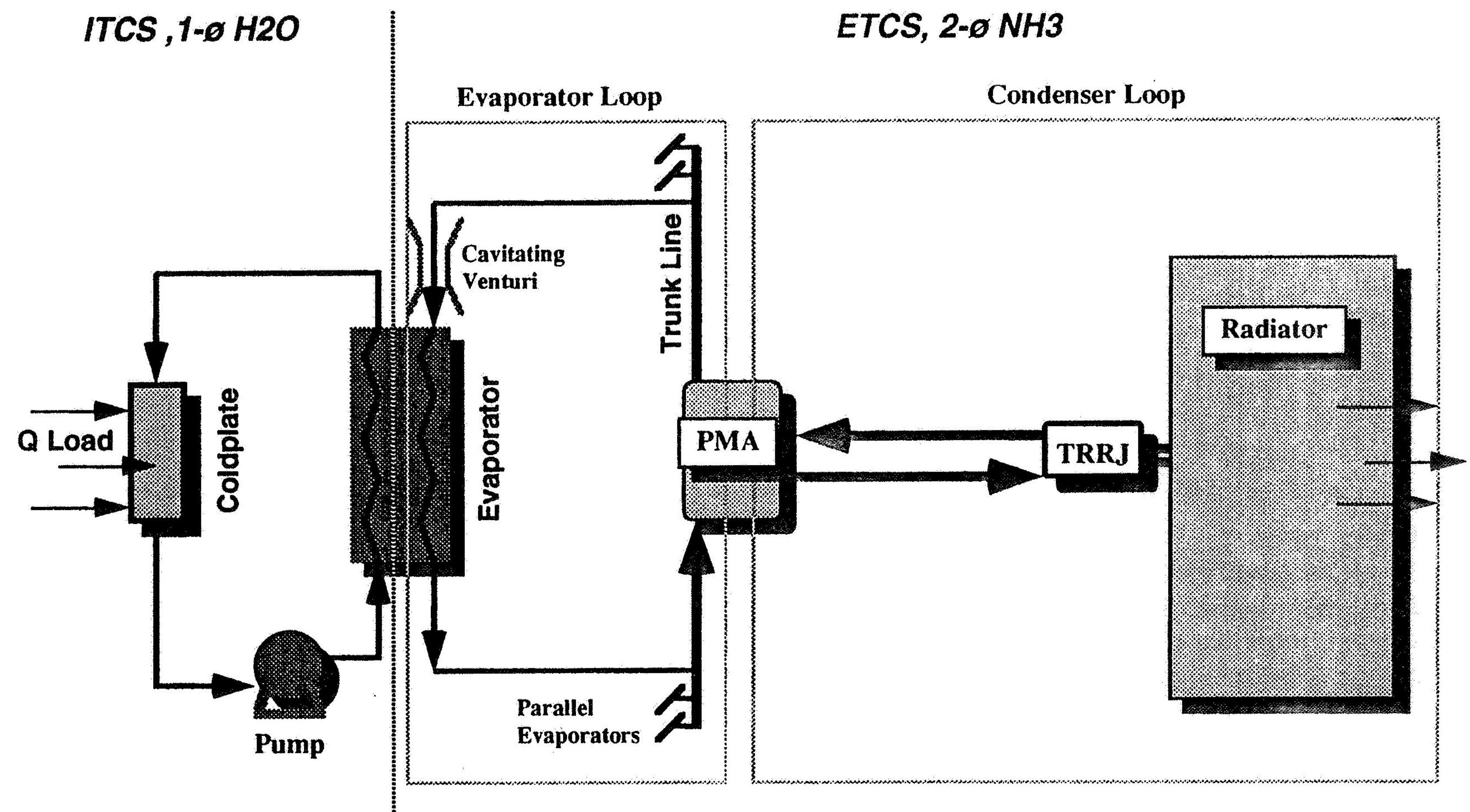
Agenda

- Baseline Configuration
- Significant Restructuring Impacts
- Evolution Goals
- Growth Paths
  - / ETCS Evaporator Loop
  - / ETCS Condenser Loop
- Enhancing/Enabling Technologies
- Conclusions

Agenda

This presentation will cover six areas. It begins with a discussion of the baseline ATCS configuration. Next, the impacts that restructuring has had on evolution is reviewed. Then the follow-on phase and evolution phase goals are briefly discussed. The growth paths that can obtain the evolution phase are defined. The impacts and desirability of each growth path are examined. Advanced technologies that could reduce these impacts are presented, and finally conclusions for this system are offered.

ATCS



ITCS ,1-ø H2O
ETCS, 2-ø NH3
Evaporator Loop
Condenser Loop
Q Load
Coldplate
Pump
Evaporator
Cavitating
Venturi
Trunk Line
Parallel
Evaporators
PMA
TRRJ
Radiator

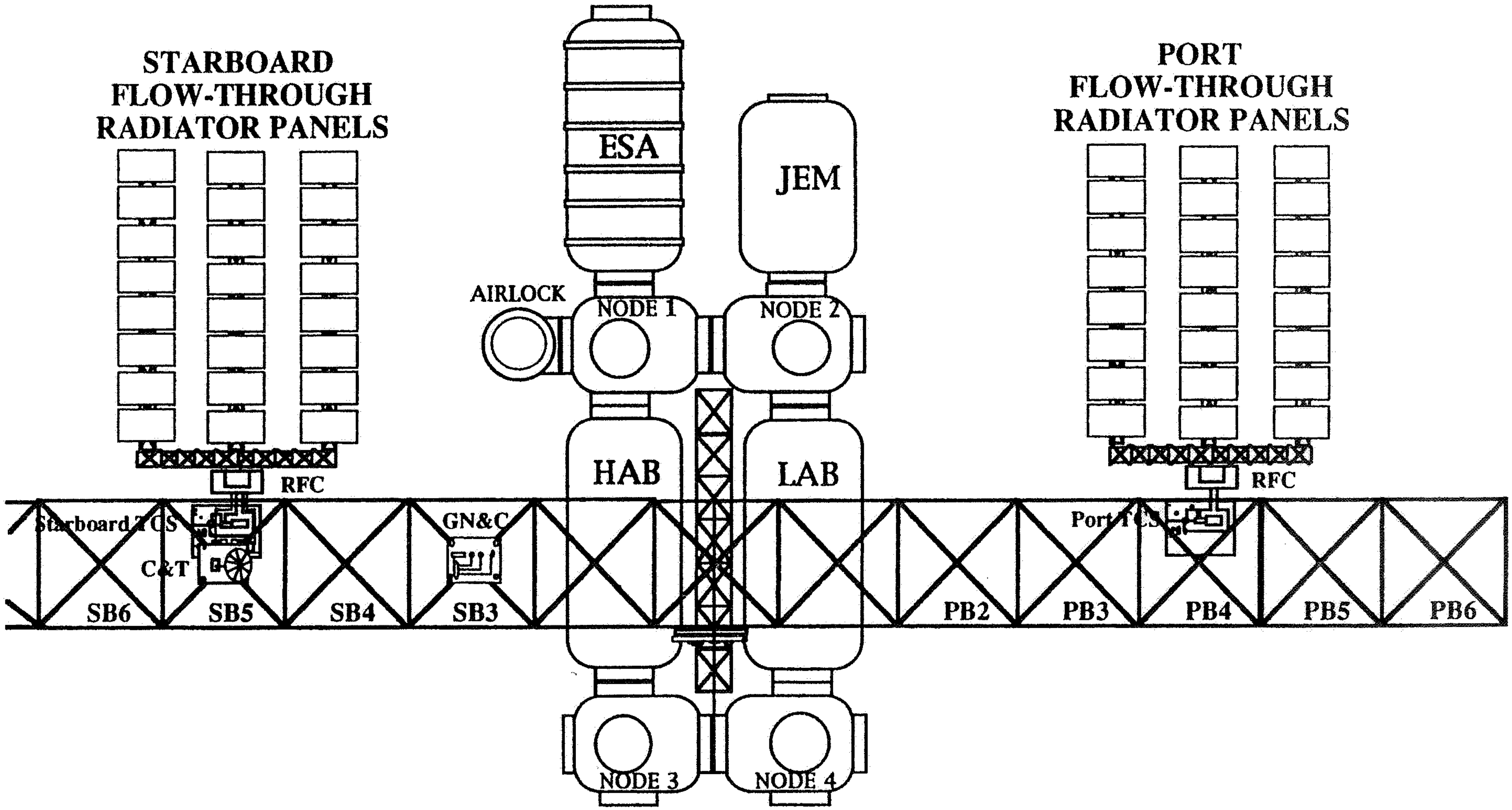
ATCS Baseline Configuration

The ATCS is divided into two subsystems.

The Internal Thermal Control System (ITCS) is a single-phase water loop located in the modules and nodes. The water loop collects heat from the cold plates and transfers it to the water/ammonia evaporator.

The central or External Thermal Control System (ETCS) uses two-phase ammonia in the external bus and radiators. The trunk line supports parallel evaporators located at the modules and nodes. As the ammonia vaporizes in the evaporators, the ETCS evaporator loop collects waste heat from the ITCS. The ammonia leaves the evaporator as a two-phase fluid. The Pump Module Assembly (PMA) separates the two phases of ammonia and transfers the vapor to the ETCS condenser loop. As the radiators reject heat to space this vapor condenses and is returned to the PMA.

PIT Configuration



Drawn By: K. Andish, April 1991

PIT Configuration

The external thermal bus is routed throughout the station by way of the Utility Distribution System (UDS). Three independent loops are used in the external thermal bus. The two 35 °F loops are low temperature buses that support the starboard flow-through radiator wing. The remaining 62 °F loop is a moderate temperature bus that supports the port flow-through radiator wing. The two phase quality of the ammonia stream keeps the external bus temperature within a seven degree setpoint during heat acquisition and rejection.

Heat is rejected by dual thermal radiator wings made up of flow-through panels that rotate for optimum thermal orientation during orbit.

The two radiator wings are coincident with the TCS fluid management equipment, which is located on mounting plates of the pre-integrated truss structure. The total EMCC heat rejection capability of the ATCS will increase from 20.6 kW at Man-Tended Capability (MTC) to 61.9 kW at Permanently Manned Capability (PMC), and finally to 82.5 kW at EMCC.

Significant Restructuring Impacts

Growth Paths

- Heat acquisition and transport growth options are similar to "Turbo" configuration.
- Heat rejection growth options have been curtailed.

Heat Rejection / Radiator Surface Area Constraints

- MT location prevents radiator wing addition in the +x direction.
- Smaller baseline truss prevents radiator wing relocation or growth in the +/- y direction due to module or PV array interference.
- Growth of radiator surface area in the -x direction at the PIT location is the only option with the baseline truss.
- Radiator wing addition to growth structure is a possible option.

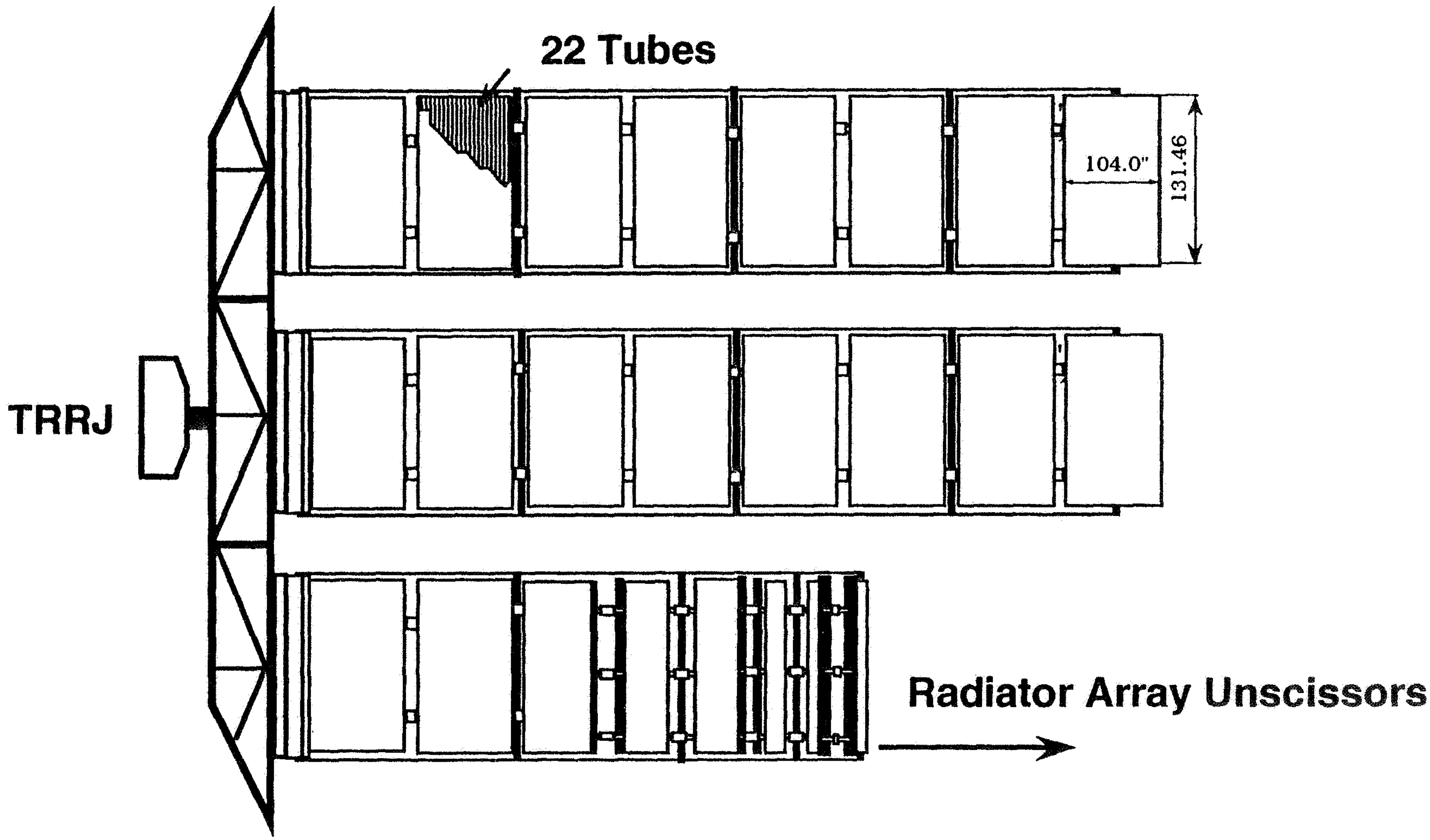
Significant Restructuring Impacts

Line addition is the most promising of the heat transport growth paths. This option is still feasible with restructuring. Because there is less space on the Pre-Integrated Truss (PIT) than the "Turbo" modular truss, the integration of the fluid lines may be more difficult.

Heat rejection growth options have been curtailed. The original evolution growth path called for modular addition of baseline technology. Radiator wings were to be placed in the +x direction (velocity vector). Wing addition in this location is no longer possible. Restructuring has placed the Mobile Transporter (MT) along the face of this truss. Real estate is not available anywhere on the now smaller baseline truss for radiator wing addition. The existing radiator wings can not grow in the y direction due to interference from the modules or PV arrays. These radiator wings could only grow in the -x direction.

Radiator wing addition would require the addition of growth structure. Non-baseline heat rejection technologies must be used, if this approach is not followed.

Radiator Wing



Drawn By: K. Andish, April 1991

Radiator Wing

The ATCS radiator wing is the only significant technology change to come out of restructuring. The direct condensing, flow-through radiators were selected over the heat pipe radiators to reduce weight, cost, and program risk.

The radiator wing contains three Orbital Replacement Units (ORU's). Each ORU has eight radiator panels with 22 tubes each. The baseline radiator is more susceptible to Micrometeorite/Orbital Debris (MM/OD) impact damage due to its flow-through design. The anticipated debris environments during the early years of station operation are considered acceptable for this design. As the debris environments become more severe, an alternate heat pipe (HP) radiator ORU could be implemented. The HP radiator is less affected by MM/OD impact because the condenser and HP fluid do not come into direct contact. Single point damage to a flow-through radiator panel would result in the loss of the entire panel. Single point damage to the current HP radiator panel design would result in the loss of 1/22 of a panel. Fluid leakage from this damage is significantly less for the HP radiators. If radiator ORU's were replaced as a maintenance item, this could benefit evolution goals. The opportunity could be used to upgrade the heat rejection capability of the radiator wing by either increasing the operating pressure or surface area of the radiator ORU. These upgrades will be discussed in detail.

ATCS Evolution

- Proposed Requirement:

  The thermal distribution system shall allow for growth proportional to the heat rejection requirement from EPS plus parasitic and metabolic loads.

- Follow-on Phase:

  / Scars are not needed

  ATCS Load = 82.5 kW

- Evolution Phase:

  / Scars are recommended
  / EPS Load = 150 kW
  / Parasitic Load > 150 kW * 0.8 = 12 kW
  / Metabolic Load = 2.5 kW for 12 crew

  ATCS Load > 150 kW + ~12 kW + 2.5 = 165 kW

ATCS Evolution

The ATCS is being design for 82.5 kW at EMCC also referred to as the Follow-on phase. In our studies, the evolution phase is assumed to be twice this value, because the EPS requirement is doubled. An exact heat rejection value cannot be determined until the DDCU load sharing is better understood. The two parameters besides EPS load that most affect heat load are the parasitic and metabolic loads..

Parasitic Load

Parasitic load is the result of DDCU inefficiency. The coldplates collect and transfer this heat to the ATCS.

DDCU efficiency is a function of load. The DDCU has a maximum efficiency of 92%, when power output is at 6.25 kW. As power output decreases from this level, DDCU efficiency decreases.

At 75 kW of power, it is not possible for all the DDCU's to operate at 6.25 kW. Twelve of the 30 baseline DDCU's could provide 75 kW of power at maximum efficiency, while the other 18 would be idling at minimum efficiency. This combination of fully loaded and idling DDCU's is the worst case scenario, and would result in an average efficiency significantly lower than 92%. The waste heat generated by the DDCU's will be larger than the 6 kW (75 kW * 8%) value for a realistic load allocation.

DDCU Heat Loss as a Function of Power Output

Power Output	Thermal Heat Dissipation
6.25 KWE	598 watts
3.0	315
1.25	163
0.001	163
0.0	50

Metabolic Load

The crew generates sensible and latent heat by metabolic processes. The minimum metabolic heat load is the amount necessary to maintain life. The maximum load is the predicted crew activity limit. The air regeneration system collects and transfers this heat to the ATCS.

The metabolic load has an expected range of 6,720 to 16,800 Btu/crew-day, and a nominal value of 11,200 Btu/crew-day

Metabolic Load = 16,800 Btu/crew-day = 0.206 kW for 1 crewmember = 2.47 kW for 12 crew

Growth Paths
ETCS Evaporator Loop

Path 1 - Size baseline trunk lines for growth

Baseline trunk lines are connected to the following:
- Path 1.a - Baseline PMA sized for evolution capacity
- Path 1.b - Upgraded PMA
- Path 1.c - Growth PMA

Path 2 - Replace baseline trunk lines with upgraded lines

Replacement trunk lines are connected to the following:
- Path 2.a - Baseline PMA sized for evolution capacity
- Path 2.b - Upgraded PMA
- Path 2.c - Growth PMA

Path 3 - Add growth trunk lines

Growth trunk lines are connected to the following:
- Path 3.a - Baseline PMA sized for evolution capacity
- Path 3.b - Upgraded PMA
- Path 3.c - Growth PMA
- Path 3.d - Growth PMA, Vapor Compression Cycle (VCC) HX

Growth Paths: ETCS Evaporator Loop

A matrix has been developed that contains the growth paths available for ATCS evolution.

For the evaporator loop, there are three possible paths. The growth heat transport can be accommodated by increasing trunk line size (Path 1), replacing trunk lines in orbit with lines of greater capacity (Path 2), or by adding additional trunk lines in orbit to support growth (Path 3).

There are three common subpaths that can be used to transfer this heat to an ETCS condenser loop. The blank underline implies more than one growth path can be followed to reach this point. The trunk line could be connected to one of the following:

- A baseline PMA that has been sized for evolution capacity. This PMA would transfer the increased load to the existing ETCS condenser loops. These loops would have to be modified for this increased capacity (Path _.a).
- An upgraded PMA that replaces the baseline one in orbit. This path also assumes the existing ETCS condenser loops are used (Path _.b).
- A growth PMA is added in orbit. This path assumes a growth ETCS condenser loop is also installed in orbit. This path will require the addition of growth structure for radiator wing addition (Path _.c).

Path _.d ties the baseline and growth PMA outlet heat loads together into the existing radiator wings by the use of a Vapor Compression Cycle (VCC) heat exchanger (HX). This subpath is only associated with Path 3. A parallel or growth condenser loop is needed for the HX interface.

Growth Paths
ETCS Condenser Loop

Path _._.1 - Surface area growth is limited to baseline radiator wing location

Path _._.2 - Radiator wing addition is possible due to growth structure

Path _._._.a - radiator surface area is held constant, temperature is increased
Path _._._.b - radiator surface temperature is held constant, area is increased
Path _._._.c - radiator surface temperature and area are increased

Path 4 - Growth modules contain independent body-mounted heat rejection systems

Growth Paths: ETCS Condenser Loop

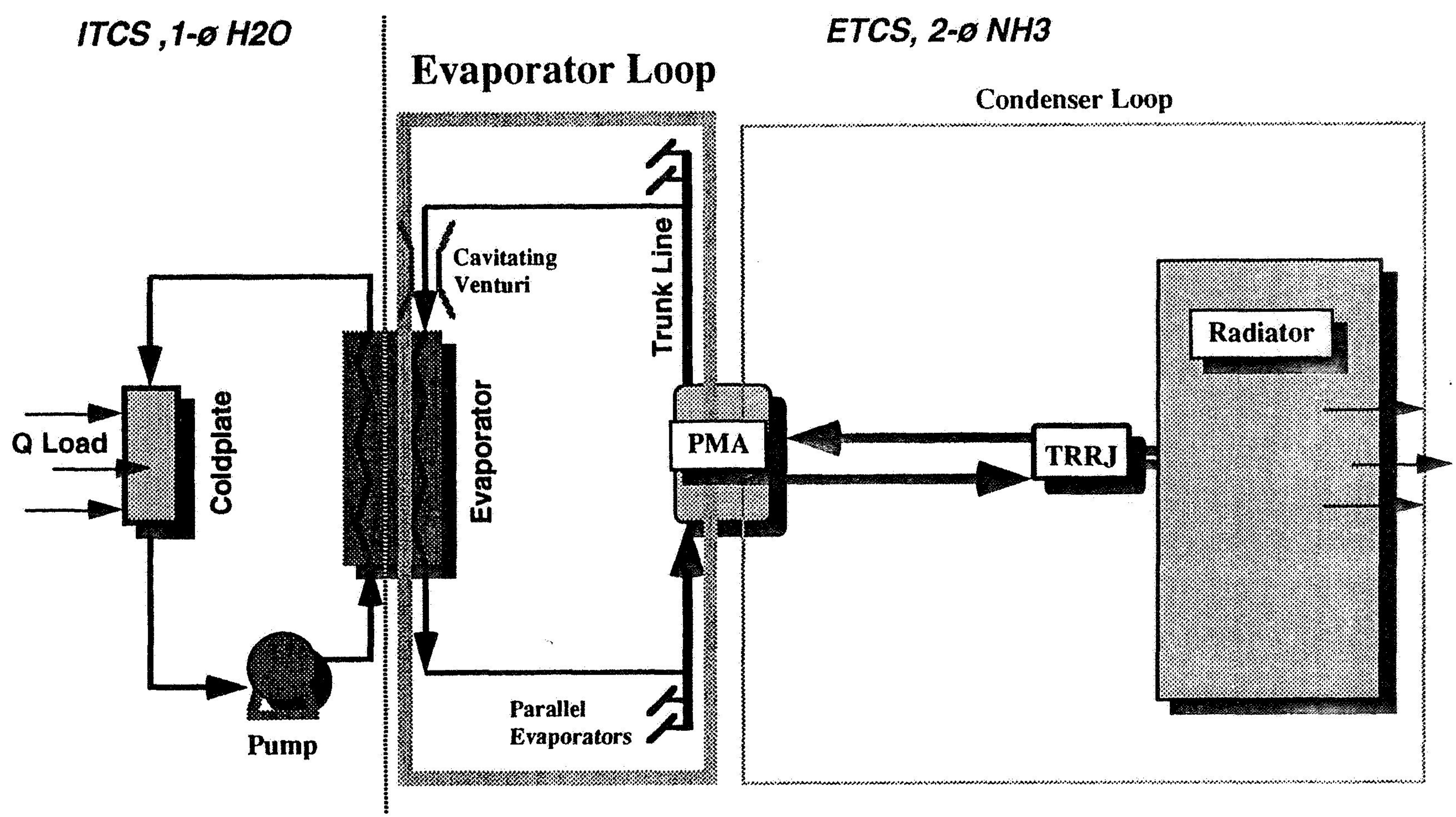
For the condenser loop, there are two distinct growth paths. Heat rejection can be increased by the modification of the existing radiator wing (Path _._. 1) and/or the addition of radiator wings due to growth structure (Path _._.2).

If the baseline radiator wing location is used, wing modifications are essential. In the case of wing addition, modifications could also be beneficial. The radiator wings could reject more heat to space if the surface temperature is increased (Path _._._.a), if the surface area is increased (Path _._._b), or if both parameters are optimized (Path _._._.c).

A fourth possible path is to have growth modules provide their own heat rejection using body-mounted radiators. This growth path is not desirable because interference from the Station environment, such as shadowing, would cause the heat rejection capability of the body-mounted radiators to be less than a centralized system could offer.

Advanced technologies, such as high efficiency low weight radiators, can be applied within the growth path matrix.

ETCS Evaporator Loop Evolution



ETCS Evaporator Loop Evolution

The next four charts will discuss the evolution of the evaporator loop.

Growth Path Impacts
ETCS Evaporator Loop

Heat Transport Line

- Path 1: Size baseline lines for evolution capacity
  - / Increase in upfront costs due to redesign
  - / Increase in upfront system weight
  - / Potential schedule impact due to redesign
- Path 2: Line replacement
  - / EVA intensive
  - / UDS tray removal
  - / UDS tray addition
  - / Increase in UDS fluids tray real estate
  - / Impact on baseline operations during modifications
  - / Potential contamination of SSF environment
- Path 3: Line addition
  - / EVA required (< 1/2 of path 2)
  - / UDS tray addition
  - / Double real estate of UDS fluids tray

Growth Path Impacts: ETCS Evaporator Loop

Each growth path has its own set of scars and related impacts to the Station.

Path 1 requires doubling the heat transport capability of baseline equipment. This path would reduce program cost and risk, but there are upfront penalties. Launch weight would increase, and the current system would have to be redesigned. This would increase cost and could result in a possible schedule slippage.

Path 2 assumes real estate is not available for line addition, and any growth would require line replacement. For the current baseline, this assumption is false. Line replacement has the worst growth path impacts and would only be considered as a last resort.

Path 3 assumes growth lines are added for the evolution phase. This path requires the addition of UDS fluid line trays in space. This assembly will require either EVA or robotic assistance. The significant impact here is system integration and assembly operations.

Growth Path Impacts (Cont.)
ETCS Evaporator Loop

Growth/Baseline Heat Rejection Tie-in Location

- Path _.a: Size baseline PMA for evolution capacity
  - / Increase in upfront costs due to redesign
  - / Increase in upfront system weight
  - / Schedule impact due to redesign
- Path _.b: PMA replacement
  - / Scar mounting brackets for an increase in PMA volume
  - / Scar real estate around PMA interface for growth line replacement
  - / Scar EPS for increased RFMD demands
  - / Impact on baseline operations during modifications
  - / EVA required
- Path _.c: PMA addition, Growth radiator wing
  - / Scar for growth structure attachment point
  - / EVA required (greater duration than Path _.b)
- Path 3.d: PMA addition, VCC HX
  - / Scar baseline truss for growth PMA addition
  - / Scar EPS for growth PMA support
  - / Scar baseline truss for VCC HX addition
  - / VCC HX integration will impact baseline operations
  - / EVA required (greater duration than Path _.b)

Growth Path Impacts: ETCS Evaporator Loop (Cont.)

As already discussed, there are four evaporator loop subpaths. These subpaths can act as the tie-in location for the baseline and growth evaporator loops if the existing radiator wing locations are used.

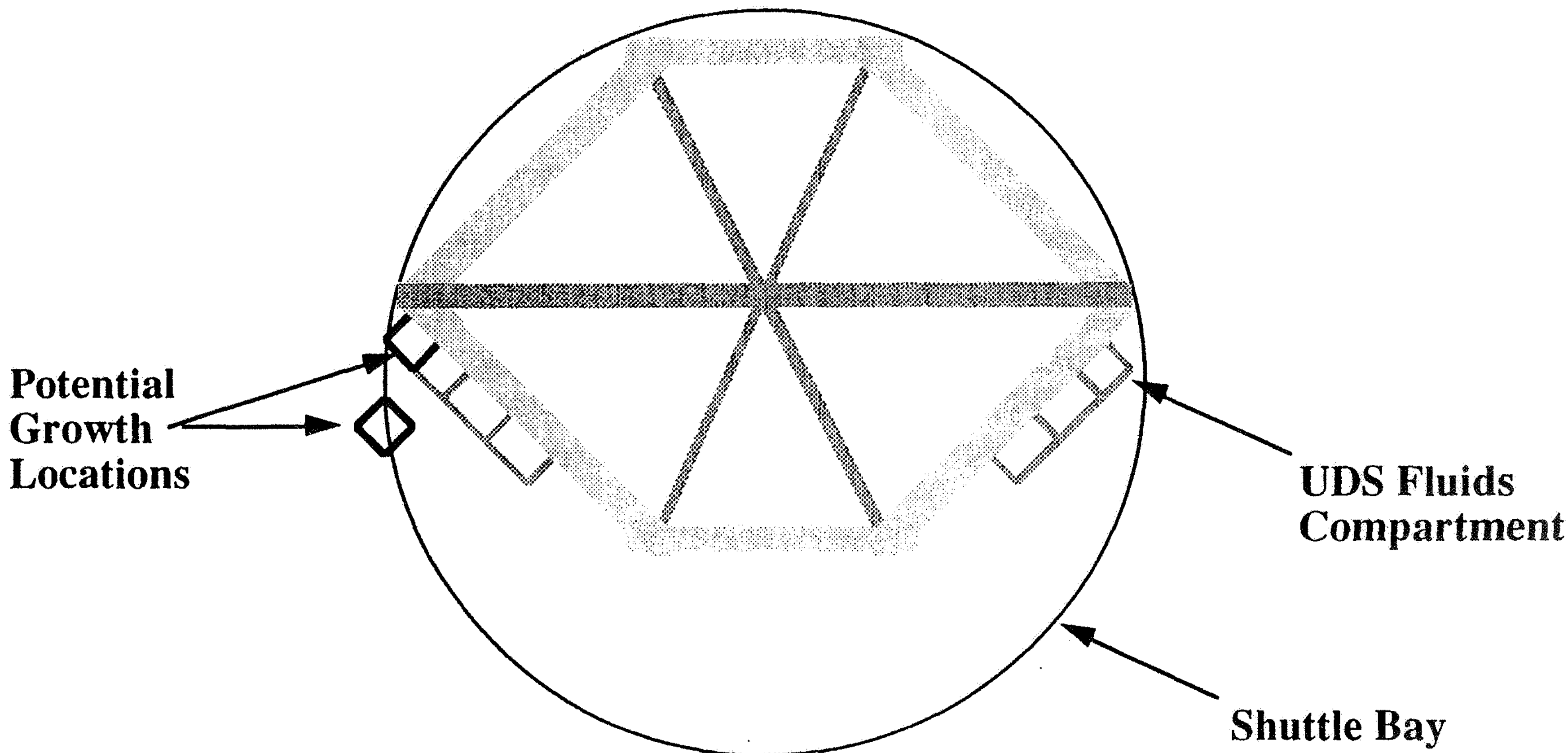
Path _.a requires doubling the heat transport capability of the baseline PMA. This path would reduce program cost and risk, but there are upfront penalties. Launch weight would increase and the current system would have to be redesigned. This would increase cost and would result in a schedule slippage due to Rotary Fluid Management Device (RFMD) redesign.

Path _.b assumes the baseline PMA will be replaced with a growth PMA on orbit. The Station must be scarred for this option. Real estate must be reserved for the larger volume the growth PMA requires. The EPS would need to provide more power than the baseline design. Each of the three buses would be shut down during their respective PMA replacement.

Path _.c assumes a parallel ATCS is added for growth. The Station would need to be scarred for structure and line attachment. Radiator wing and UDS tray could be delivered as part of a growth PIT section. EVA may be required for structure attachment and running UDS lines to the attachment point.

Path 3.d requires real estate and EPS scars to support a growth PMA that ties into the existing radiator wing location. The installation of the VCC HX would shut down the bus while it was being added.

Growth Trunk Lines: Path 2
ETCS Evaporator Loop



Generic Utility Inboard Profile

Growth Trunk Lines: ETCS Evaporator Loop

As will be discussed later, line addition is the most likely growth path. The baseline PIT is densely packed due to the Shuttle bay envelope restriction. This restriction does not exist for growth components added on orbit, and thus opens up real estate for UDS fluids tray addition. There are two potential locations for the growth tray. If the tunnion pins used for launching the PIT are removed, the growth tray can be placed next the the baseline tray. The tray can also be elevated above the baseline tray.

Growth Path Desirability
ETCS Evaporator Loop

	Desirability
Heat Transport Line	
• Path 1: Size baseline lines for evolution capacity	1
• Path 2: Line replacement	3
• Path 3: Line addition	2
Growth/Baseline Heat Rejection Tie-in Location	
• Path _.a: Size baseline PMA for evolution capacity	1
• Path _.b: PMA replacement	2
• Path _.c: PMA addition, Growth radiator wing	1
• Path 3.d: PMA addition, VCC HX	3

Growth Paths Desirability: ETCS Evaporator Loop

Desirability is a subjective engineering assessment of the growth paths which considers integration, risk, and weight parameters. More analytical assessments are being developed.

Path 1 would have the lowest risk and cost to the program. The impediment to this option is the present fiscal reality and schedule requirements.

Path 2 has the highest risk and cost of this group. It is a last resort option.

Path 3 is the compromise option. Its allows future evolution without placing undue cost or schedule impacts on the baseline.

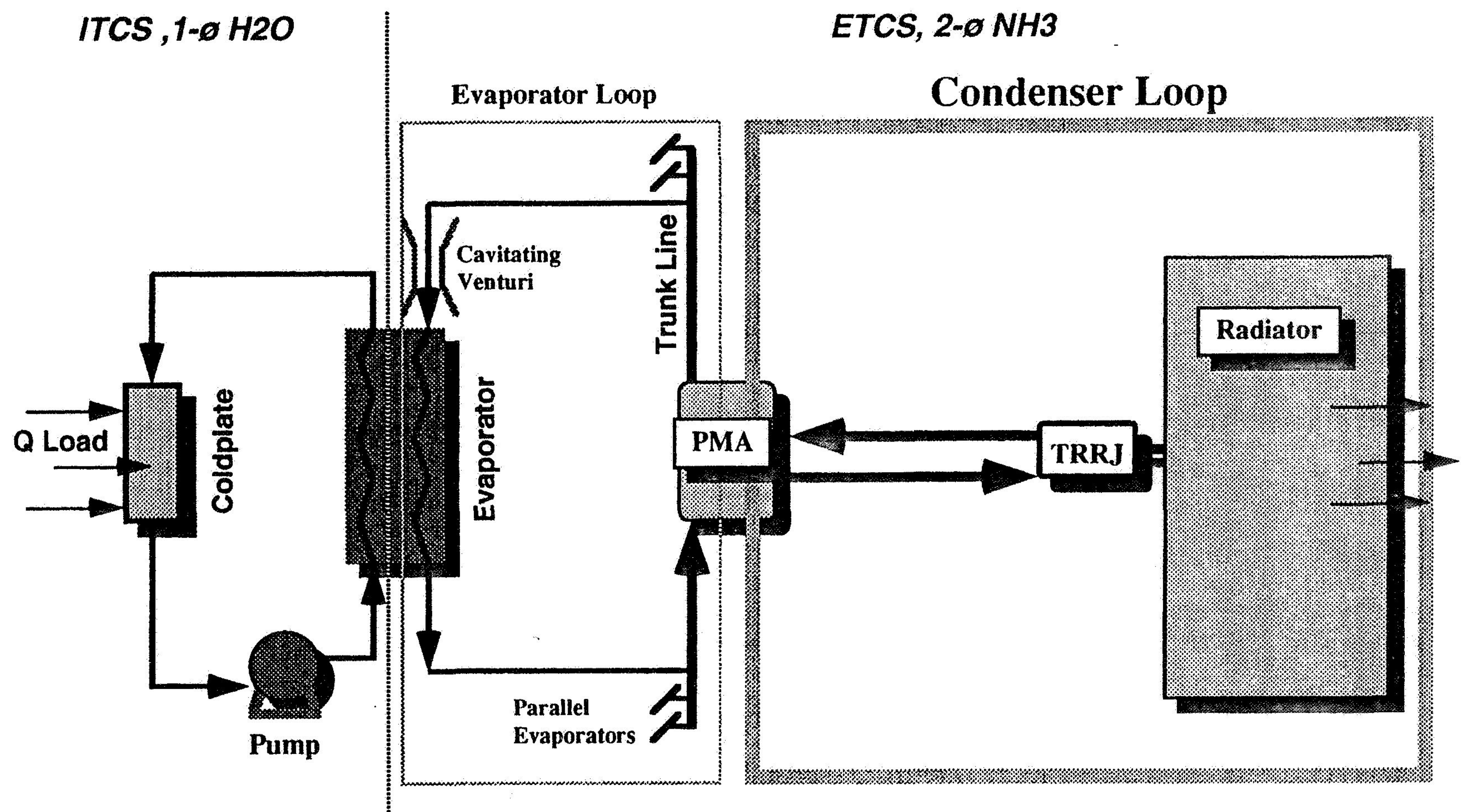
Path _.a would have a low risk and cost to the program. The impediment to this option is the present fiscal reality and the schedule impact involved with redesign.

Path _.b is a promising option if the baseline radiator wing location must be used.

Path _.c this option is rated the same as Path _.a, because the integration of a growth PIT structure containing an ETCS condenser loop into the Station would involve less EVA than upgrading the baseline ETCS condenser loop.

Path 3.d is less efficient than Path _.b at about the same level of cost and risk. This path is promising, if a heat pump option is selected and an expansion valve upstream of the PMA is considered a risk or a higher performance fluid is used inside the VCC.

ETCS Condenser Loop Evolution



ETCS Condenser Loop Evolution

The next seven charts will discuss the evolution of the condenser loop.

Growth Path Impacts
ETCS Condenser Loop

Heat Rejection Location

- Path _._.1: Surface area growth is limited to baseline rad. wing location
  - / Impact on baseline operations during modifications
  - / EVA required
- Path _._.2: Radiator wing addition is possible due to growth structure
  - / EVA required

Heat Rejection Parameters

- Path _._._.a: Radiator surface temperature is increased
  - / Scar for vapor compressor and expansion valve addition
  - / Scar EPS for vapor compressor support
  - / SSF environment impact due to radiator temperature increase
  - / Replace lines downstream of PMA or VCC HX
  - / Replace flow-through radiator ORU's (maintenance item)
  - / TRRJ impact
  - / Schedule impact due to development and testing of vapor compressor

Growth Path Impacts: ETCS Condenser Loop

There are two distinct growth paths for the condenser loop.

Path _._.1 is the modification of the existing condenser loop to obtain evolution heat rejection capability. This path would impact operations since each loop would be shut down during upgrades. The EVA required could be larger than Path _._.2.

Path _._.2 is the addition of a condenser loop to a PIT growth structure. Baseline operations would not be curtailed during condenser loop addition. EVA would be required. A growth structure attachment point scar is needed.

Both of these paths could impact drag, structural dynamics, and an increased potential for micrometeorite collision. These impacts are currently being modeled.

The three subpaths modify the radiator wings to obtain greater heat rejection capability.

Path _._._.a uses a heat pump to increase the radiator surface temperature. A scar for heat pump equipment addition is needed. The EPS would need to be scarred to deliver more power to the RFMD. Baseline equipment inside the VCC would have to be replaced to account for higher operating pressures. If the radiator ORU's are replaced as a maintenance item, their upgrade would not significantly impact the evolution program. The effect of the heat pump on the Station's thermal environment is currently being modeled.

Growth Path Impacts (Cont.)
ETCS Condenser Loop

Heat Rejection Parameters (Cont.)

- Path _._._.b: Radiator surface area is increased
  - / Scar for increased load to structure
  - / Replace TRRJ
  - / GN&C impact
- Path _._._.c: Radiator surface temperature and area are increased
  - / Scar for vapor compressor and expansion valve addition
  - / Scar EPS for vapor compressor support
  - / SSF environment impact due to radiator temperature increase
  - / Replace lines down stream of PMA
  - / Replace Radiator ORU's
  - / Replace TRRJ
  - / Schedule impact due to development and testing of vapor compressor
  - / Scar for increase load to structure
  - / GN&C impact

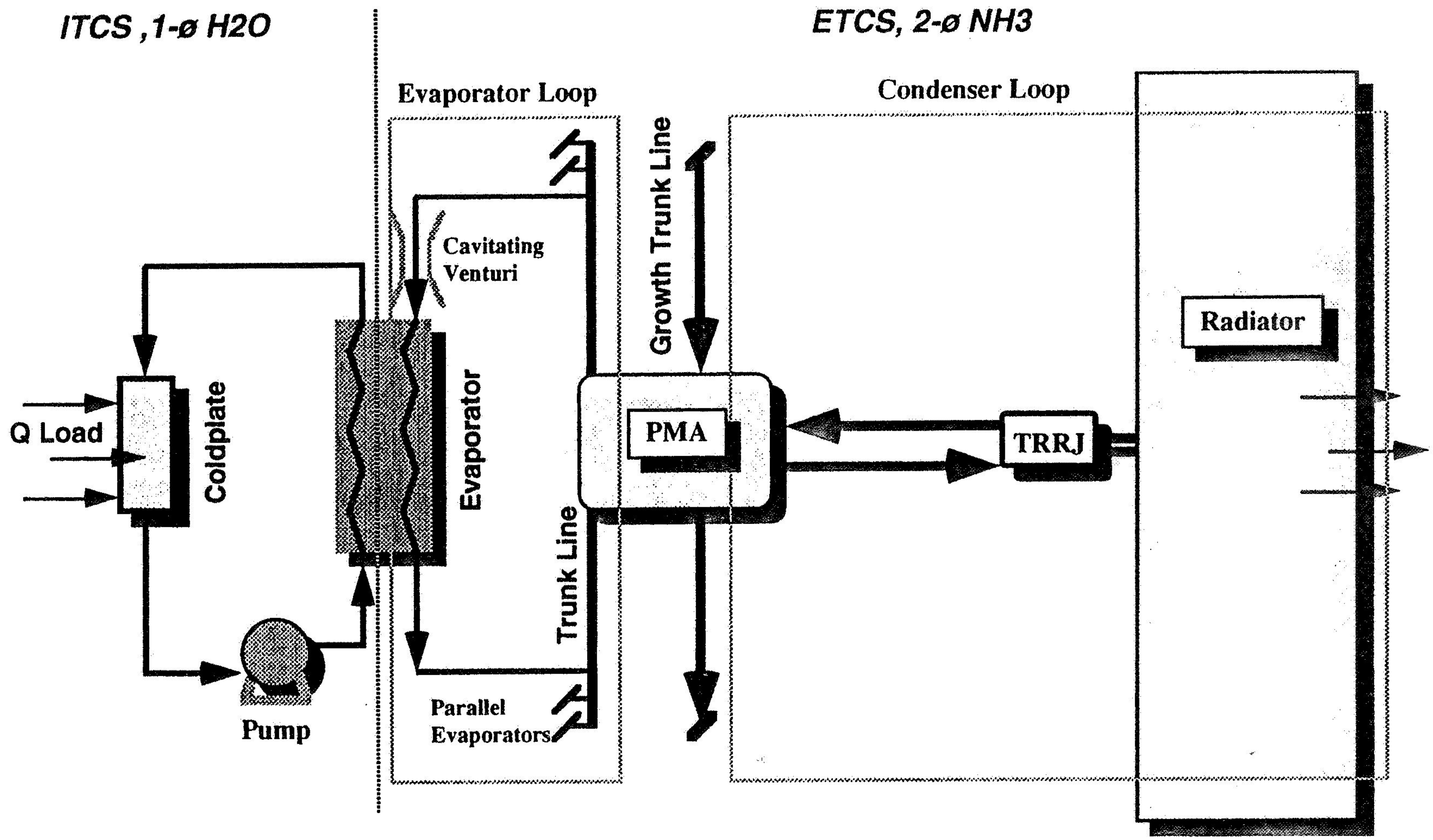
Growth Path Impacts: ETCS Condenser Loop (Cont.)

Path _._._.b increases the surface area of the radiator in the -x direction. Unless a light weight radiator ORU is developed, the TRRJ would have to be replaced. Baseline radiator ORU structure cannot be doubled in length. The resulting frequency would violate Guidance, Navigation and Control (GN&C) requirements.

Path _._._.c is the optimization of greater radiator surface area and higher temperature. Since the impacts for both Path _._._.b and _._._.c are listed, it appears this is an undesirable option. The opposite is true. By optimizing each parameter, we can hopefully diminish the severity of each impact on the Station. For example, the radiator surface area could be increased until the frequency limit is reached. Then the heat pump could raise the heat rejection to the evolution value. This would reduce the power requirement and structural impacts.

Modification of Existing Radiator Wings

Increase Radiator Area in -x Direction: Path 3.b.1.c



- **GN&C and structural loads are a concern**

Modification of Existing Radiator Wings
Increase Radiator Area in -x Direction: Path 3.b.1.c

In this example, the baseline and growth evaporator loops are parallel systems. They tie into the same condenser loop using an upgraded PMA. Depending on the PMA design, there may be an impact on the lines in the condenser loop. As mentioned earlier, the radiator ORU's may be replaced before the evolution phase as a maintenance item. At that time, it may be possible to use radiator ORU's with greater surface area in the -x direction. Unless an advanced lightweight radiator is used, the TRRJ will have to be replaced.

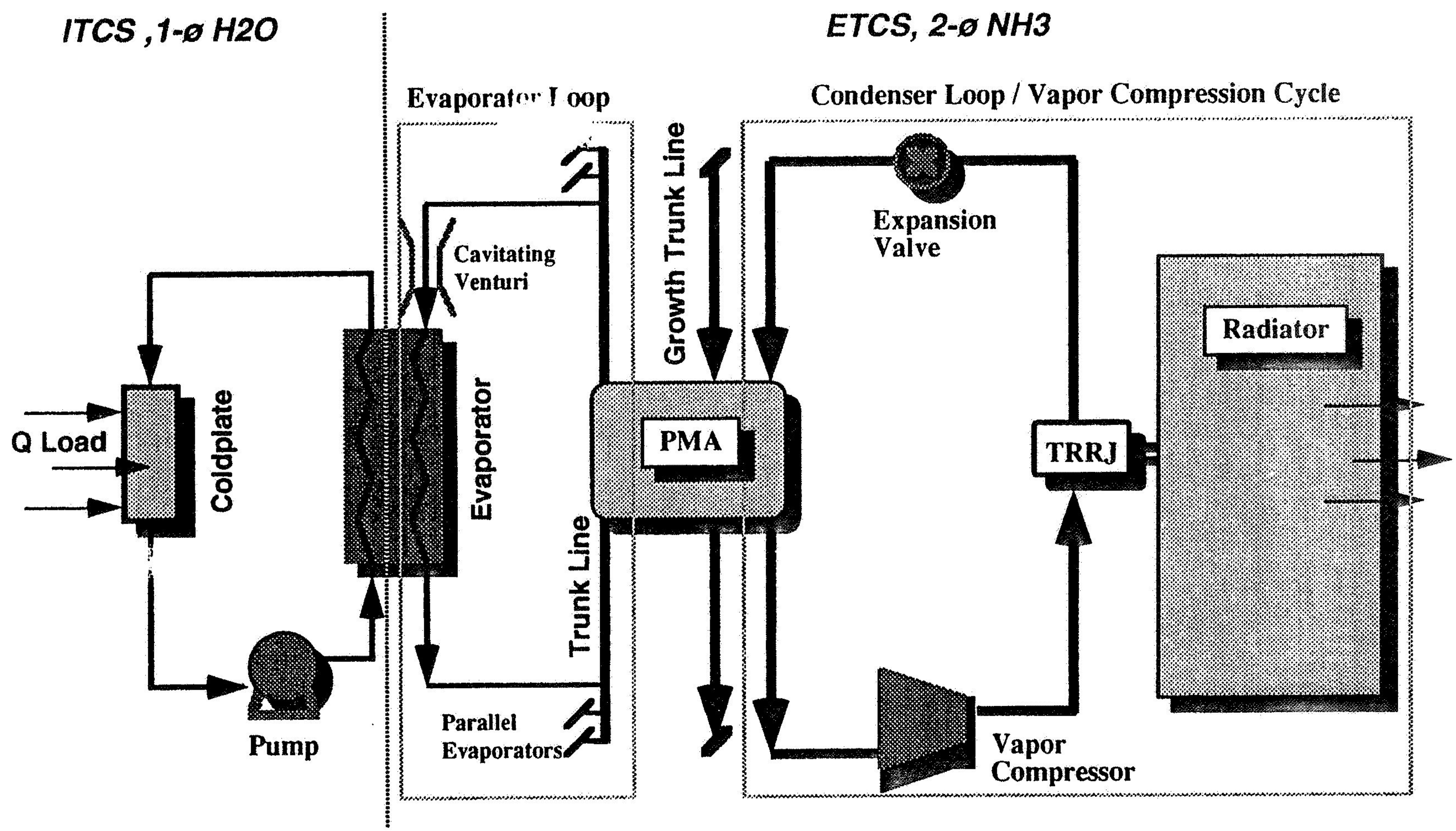
The following are potential limiting factors for growth in the -x direction:

- Frequency
- Load
- Drag
- Plume impingement

Frequencies of the radiator panel structure are proportional to the square of the length. Currently this frequency is about 1/4 Hz. Doubling the length of the radiator ORU may produce a frequency of about 1/16 Hz. This could present a problem because frequencies lower than about 1/10 Hz are of concern to flight control people (JSC 31000). Structural scars would be necessary.

Modification of Existing Radiator Wings

Heat Pump Integration into ATCS by Upgraded PMA: Path 3.b.1.a



- 18 kW of power is required to reach the evolution goal

Modification of Existing Radiator Wings
Heat Pump Integration into ATCS by Upgraded PMA: Path 3.b.1.a

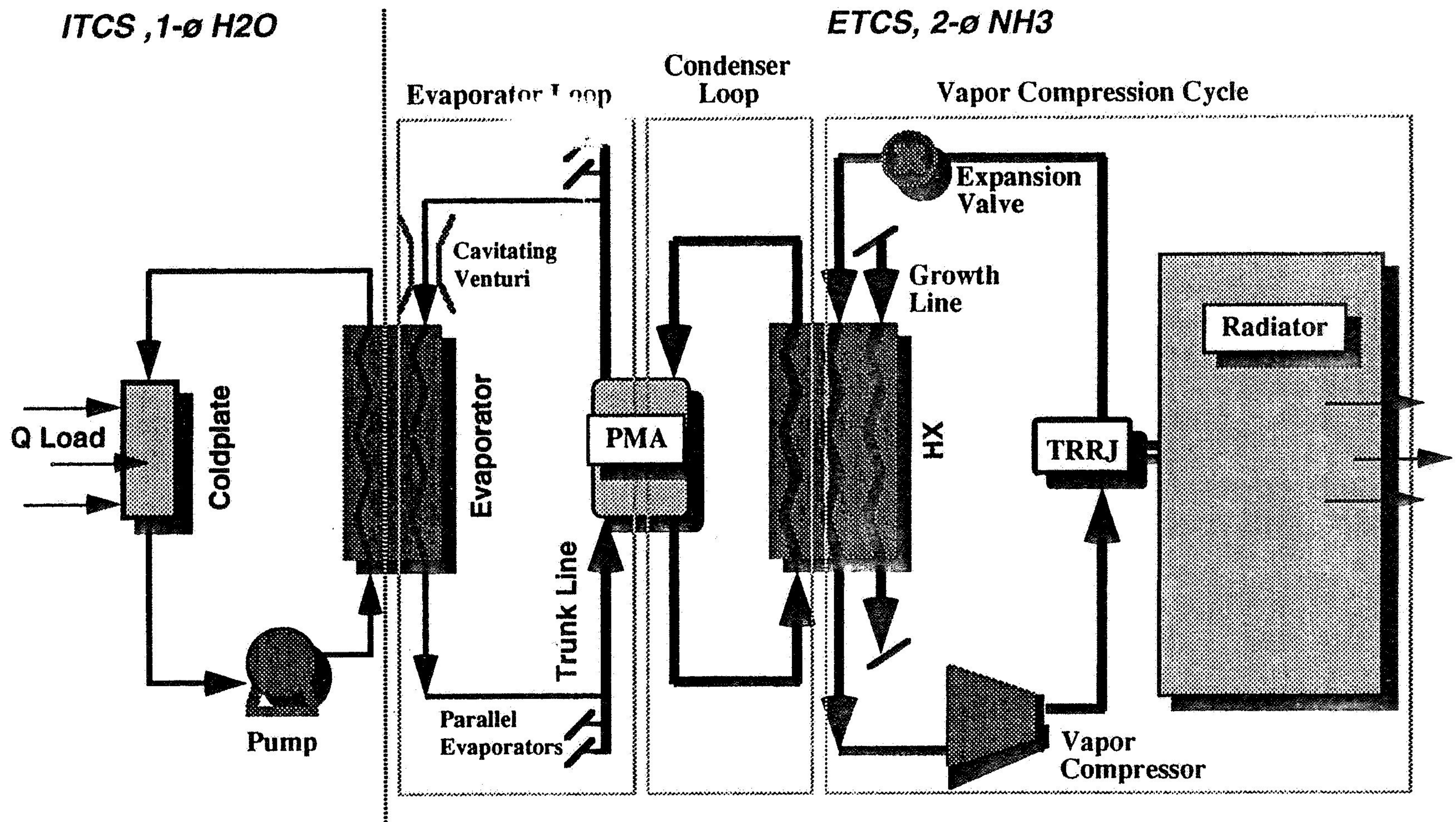
Again, the baseline and growth evaporator loops are parallel systems. They tie into the same condenser loop using an upgraded PMA.

By the addition of the vapor compressor and expansion valve, the condenser loop has become a VCC. As the vapor compressor raises fluid temperature it also raises the pressure. The operating pressure of the system is 120 psi (Saturated ammonia at 64 °F). With this pressure limit, the VCC lines and radiator ORU's would have to be replaced. The impact on the baseline TRRJ is undetermined. The maximum operating pressure of the system is 286 psi (Saturated ammonia at 120 °F). This is a transient or start-up pressure. The system will be pressure vessel tested at this pressure. If the VCC could be operated at 286 psi, the lines, TRRJ, and radiators would not need to be replaced due to heat pump operations.

This Path uses an upgraded PMA which is the most efficient method of using a common heat rejection location for the baseline and growth heat loads. The evolution phase would require 18 kW of power to run the vapor compressor.

Modification of Existing Radiator Wings

Heat Pump Integration into ATCS by Growth HX: Path 3.d.1.a



• **19 kW of power is required to reach the evolution goal**

Modification of Existing Radiator Wings
Heat Pump Integration into ATCS by Growth HX: Path 3.d.1.a

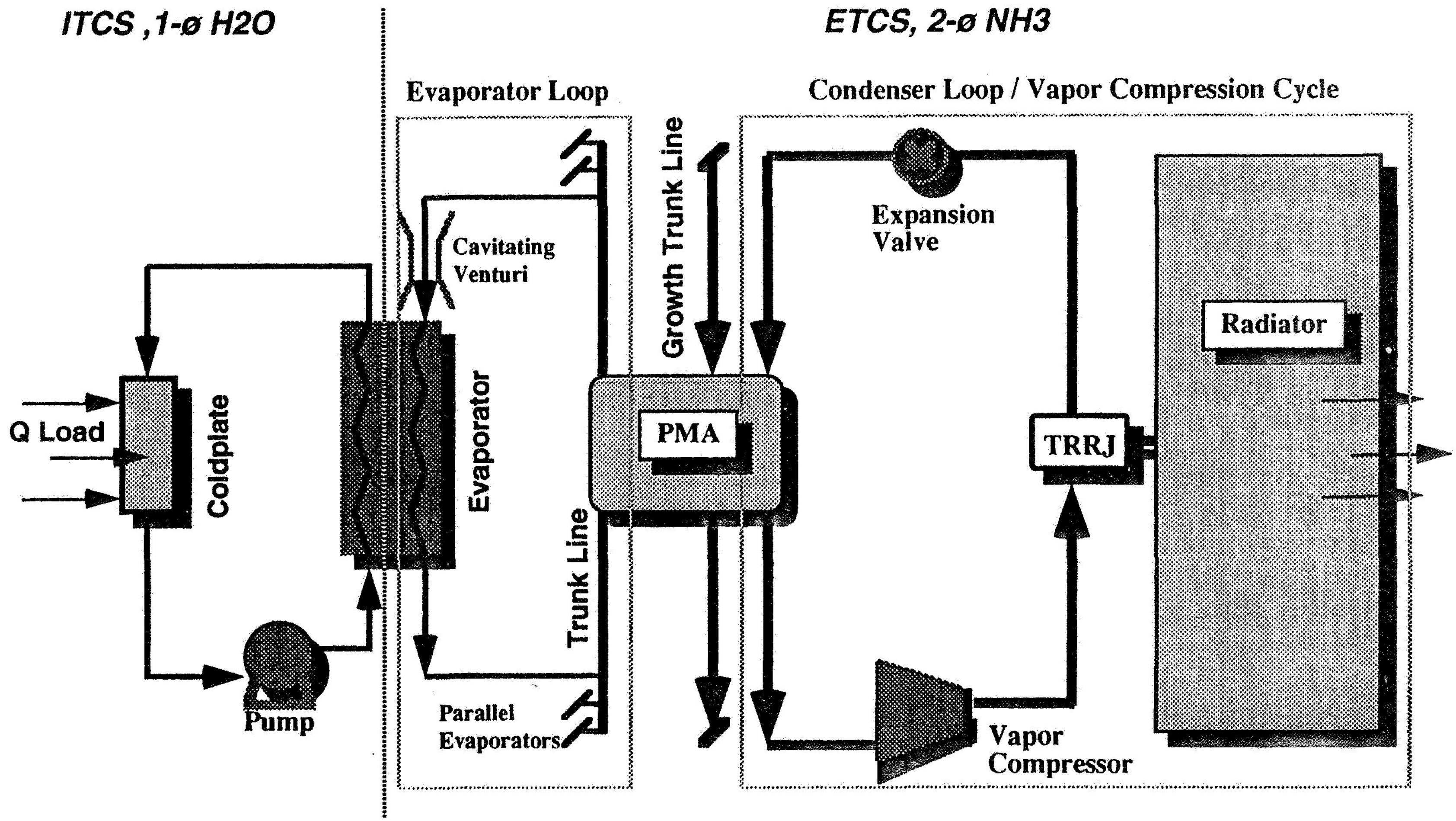
In this path a parallel growth evaporator and condenser loop is added to the ATCS. The condenser and VCC loops are distinct. In order to use the same radiator wing, the baseline and growth condenser loops tie together with a growth HX downstream of the PMA's. A 5 °F temperature drop across the VCC HX is assumed. Due to this temperature drop, more power is consumed by the vapor compressor to obtain the same heat rejection capability as Path 3.b.1.a.

Path 3.d.1.a has two advantages over Path 3.b.1.a. The growth HX isolates the the VCC from the rest of the ATCS. This protects the PMA in case of an expansion valve failure. It also allows the investigation of an alternate fluid that may have higher performance capabilities within the heat pump operating parameters, or a lower pressure that allows the use of baseline equipment.

The evolution phase would require 19 kW of power to run the vapor compressor.

Modification of Existing Radiator Wings

Increase Radiator Area/Heat Pump Integration: Path 3.b.1.c



- **Optimization of the two parameters is the most promising of the existing radiator wing modification options**

Modification of Existing Radiator Wings
Increase Radiator Area / Heat Pump Integration: Path 3.b.1.c

The power consumption that the vapor compressor requires to reach the evolution phase is high. An ATCS / EPS trade study is being conducted to determine the growth balance between these two systems.

Path 3.b.1.c is a promising option in that the optimization of greater area and higher temperature may prevent a limiting parameter from becoming a "show stopper". A limiting parameter is a parameter that would require a significant redesign or alteration in order to proceed with growth. This option increases the surface area until the limiting parameter, possibly frequency, is reached. The heat pump is then used to enhance heat rejection. The greater surface area will decrease the power needed to reach the evolution phase.

Growth Path Desirability

ETCS Condenser Loop

	Desirability
Heat Rejection Location	
• Path _._.1: Surface area growth is limited to baseline radiator wing location	2
• Path _._.2: Radiator wing addition is possible due to growth structure	1
Heat Rejection Parameters	
• Path _._._.a: Radiator surface temperature is increased	2
• Path _._._.b: Radiator surface area is increased	2
• Path _._._.c: Radiator surface temperature and area are increased	1

Growth Path Desirability: ETCS Condenser Loop

Path _._.1 would require less weight and have less structural impact on the Station than Path 2. The advantage of radiator wing addition is that it requires less EVA operations because much of the integration can occur on the ground.

If Path _._.1 is used, Path _._._.c is the favored subpath because it decreases the severity of the upgrade impacts.

Enhancing/Enabling Technologies

General Requirements

- Increase ATCS capacity while occupying less real estate than growth baseline technology would at the same heat rejection level.
- Maintain power consumption within realistic parameters.
- Limit technology research and investment to available development time frame and funding.

Heat Acquisition

- Advanced evaporator technology

Heat Transport

- Two-phase pump technology
- Distribution line technology

Heat Rejection

- Light weight deployable heat pipe radiator ORU's
- High efficiency heat pump technology
- Heat storage

Enhancing/Enabling Technologies

Advanced technologies can enhance the growth paths by removing some volume and weight impacts.

The following are advanced technology requirements:

- Increase ATCS capacity while occupying less real estate than growth baseline technology would at the same heat rejection level.
- Maintain power consumption within realistic parameters.
- Limit technology research and investment to available development time frame and funding.

Heat Acquisition

- Develop high heat flux, low pressure drop HX's to decrease weight, volume, and power.

Heat Transport

- Develop a pump with lower power consumption and higher reliability for the increased flow rates associated with higher heat rejection.
- Develop low-leakage quick disconnects and non-permeating ammonia lines which are compatible with robotic assembly.

Heat Rejection

- Increase heat rejection capability of SSF through the development of high efficiency lightweight fins. As the SSF environment degrades, replace flow-through radiator ORU's with heat pipe radiator ORU's to decrease the potential for ammonia loss due to impacts . Develop an extended-life surface coating to allow for radiator design with prolonged beginning-of-life properties.
- Develop high temperature and pressure heat pipes which allow the heat pump to run more efficiently. Develop very high capacity heat pipes to enable greater transport capacity than current designs.
- Develop heat pump systems which operate in a reduced gravity environment. Heat pump technology significantly reduces radiator area.
- Develop a high density heat storage subsystem for heat load leveling to accommodate peak loads. Heat storage reduces radiator area needed for peak loads.

Conclusions

Heat Transport Line Addition

- Real estate is available for line addition.
  - / Impacts due to line addition are being determined

Modification of Existing Radiator Wings

- The ATCS evolution goal can be obtained by the use of a heat pump.
  - / The EPS impact is significant.
  - / A EPS/ATCS trade study is in work.
- Doubling the radiator surface area using baseline technology will violate GN&C requirements.
- An optimization study on increasing radiator temperature and area is in work.

Radiator Wing Addition

- Addition of PIT structure containing radiator wings is a promising approach.
  - / Structural dynamics and GN&C impacts are under evaluation.

Conclusions

The ATCS evolution goal can be obtained. Studies continue to determine the minimum impact growth path.

The reservation of real estate for growth *structure attachment*, upgraded PMA volume, and UDS fluid tray *addition are the suggested* minimum impact scars. These scars would preserve the current growth path options. Structural dynamics studies are being conducted to determine additional scars.