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EXTERNAL TANK GH_2 VENT ARM

Garland E. Reichle
NASA-KSC
KSC, Florida

and

Charles W. Glassburn
Planning Research Corp.
KSC, Florida

ABSTRACT

Because the venting of free hydrogen gas to the atmosphere presents an extremely hazardous situation, it was necessary to devise a means for safe, controlled venting of the Shuttle external tank (ET) gaseous hydrogen (GH_2) during and after liquid hydrogen (LH_2) tank loading. Several design concepts that were considered initially were discarded as unfeasible because of vehicle weight restrictions, high cost, and because the proposed structure was itself deemed a hazard due to the vehicle's nonvertical launch trajectory. A design concept employing a support structure/access arm attached to the Fixed Service Structure (FSS) was finally selected. The various design problems resolved included vent arm disconnect/drop interference, minimizing refurbishment due to launch damage, disconnect reliability, vehicle movement tracking, minimizing vent line pressure drop, and the presence of other vehicle services at the same centralized supply area. Six launches have proven the "system" to be reliable, efficient, and of nearly zero refurbishment cost.

INTRODUCTION

After a device or system has been developed, even we engineers who were involved in the development sometimes tend to look at the end product in its most obvious and most simplified form without thinking about how it got to be what it is. In almost all cases (be it a washing machine, car, house, or Shuttle system), that end product has evolved. The evolution is initiated by a need, which in turn causes development facets which we label design concept, analysis, hard design, fabrication, testing, and utilization. In between are literally hundreds of steps, decision points, and iterations that influence the end product. The most obvious major influences, though, are requirements, requirement changes, design accuracy as proven by test, and subtle operational changes that only become visible during the testing and operations application.

Such complexity as noted above is related in this paper on the Space Shuttle ET hydrogen vent arm system. The history of how that system evolved is an interesting blend of requirements and technology utilization.

The basic requirement that initiated the vent arm design effort was, and still is, to provide a controlled means of safely venting the GH_2 that is boiled off in the Shuttle LH_2 ET during and after LH_2 loading. This paper relates how that requirement was met. We will start where the initial need was first delineated and the challenge set. We will then progress through each step of the evolution to relate what was done and why, and will conclude with the present system.

THE CHALLENGE

As noted earlier, the basic requirement was to safely vent the GH_2 that is boiled off during and after ET LH_2 loading. This translated into more specific requirements as follows:

- Provide a system to transfer the GH_2 boiloff to cross-country vent piping and thence to a burn pond.
- Ensure that the system is connected and operable until Shuttle launch is certain.
- Track all vehicle motions due to wind, solar, cryo, or other effects.

A secondary (but important) requirement was to provide an intertank purge system. This was never a design driver, but it is noted herein because the purge system was always considered to be coincidental with the GH_2 vent system. The systems physically had to go to the same vehicle area and could thus physically be (literally) tied to each other.

CONCEPT I

The initial concept was a straightforward and simple venting method. As shown in figure 1, the system would pipe the GH_2 directly from the top of the LH_2 tank down the side of the ET to a rise-off umbilical disconnect system in a tail service mast (TSM). From there, the GH_2 would be piped around the Mobile Launcher Platform (MLP) to the LH_2 disconnect tower and then to the burn pond.

Although this concept was simple, it was shelved rather quickly. At the same time the concept was being developed, Shuttle weight was becoming more and more a prime design driver. In the concept's final form, the weight of the piping, insulation, and tunneling was considered excessive unless no other viable alternative could be found.

CONCEPTS II AND III

The obvious approach to reducing vent system and purge system weight was to pipe directly from/to the intertank area. The major portion of the piping system's weight, then, would not be a direct part of the Shuttle. To do this would require a new umbilical plate, some sort of hanging or extended piping, and a disconnect method. Two concepts were thence developed which utilized tall structures to satisfy the accompanying vent and purge lines location, type of routing, and control needed. Concept II is shown in figure 2. It would utilize a new tower that would be built on the north end of the MLP. Concept III is shown in figure 3. It would utilize the FSS as its design base, namely, one corner of the 203-ft level. Both concepts first used the traditional horizontal swing-away umbilical system. However, in both cases, layouts and articulation analyses showed that the lengths of access arms needed, masses of the arms, and amount of rotation needed versus time to rotate for T-0 operations were all incongruent with design of a practical system. Thus, the drop-away umbilical-line approach was used, as shown in figures 2 and 3.

Both concepts had to meet the same physical restrictions of the Shuttle. These were: track the vehicle motions (regardless of cause), impose minimum forces on the Shuttle, and establish disconnect reliably, all without harming the vehicle. As the concepts developed, it became apparent that another requirement existed. The vehicle liftoff is not just up, but it also has an associated drift. Thus, whatever support structure was to be used and the vent and purge systems themselves could not be in the way of the vehicle. The restrictions on the physical location of Concept II's tower on the MLP were such that the tower would interfere with Shuttle liftoff. That in itself was enough to eliminate Concept II from further consideration. Added to this was the fact that the MLP would have to have major (expensive and technically undesirable) modifications to its north end to support the tower.

Concept III remained, then, as the most viable basic concept. As figure 3 shows, it consisted of a fixed arm, a retractable access (swing) arm for vent line hookup, and a vent line consisting of flexible and hard sections. (The intertank purge line would be piggyback.) The vent line was to be disconnected with a conventional mechanical advantage mechanism, i.e., a "hockey-stick" device, activated at the proper time by use of a lanyard. The vent line then would drop in a guided path. It would be expendable and thus be replaced after each launch.

At this point in time, many situations seemed to develop almost simultaneously. Studies of other ET systems kept resulting in more and more systems and requirements being added to the "vent arm assembly." Improvements in systems control, vehicle weight reduction, physical limitations or improvements, and/or safety aspects were the design drivers for these new systems requirements. It became apparent that a centralized access ground support equipment (GSE) grouping was needed. For example, GSE ET liquid oxygen (LOX) vent valve control was deemed necessary, so the pneumatic and electrical systems for that control were routed with the vent arm. Range safety needs (electrical), nose cone purge (pneumatics), ET instrumentation (electrical), and anti-icing/bipod heater power/control (electrical) were other needs routed with the vent arm. All of these, of course, affected the umbilical plate design itself and design iterations thereof. In addition, the access hatch to get into the intertank area was moved to the swing arm area to allow access on more than a contingency/emergency basis.

As the "group system" grew in total systems being accommodated, studies continued on the vent line itself. The line was sized several times. This was not an easy task because the diameter(s) had to be minimum to allow the total line to be manageable, hard sections were needed to support all of the pneumatic lines and electrical wires that were by then being routed with the vent line, and flexible sections were needed to account for vehicle tracking and similar movement aspects; yet the pressure drop through the line had to be minimal. (0.5 pound per square inch differential (psid) was the final design goal for the total vent line from the umbilical plate to the burn pond.)

One vent study showed that the line and its umbilical plate would, when released, scrape the side of the ET -- even if the vehicle did not "move into" the plate at disconnect. This situation forced a design change to provide for linear retraction of the vent arm at disconnect before the line would be

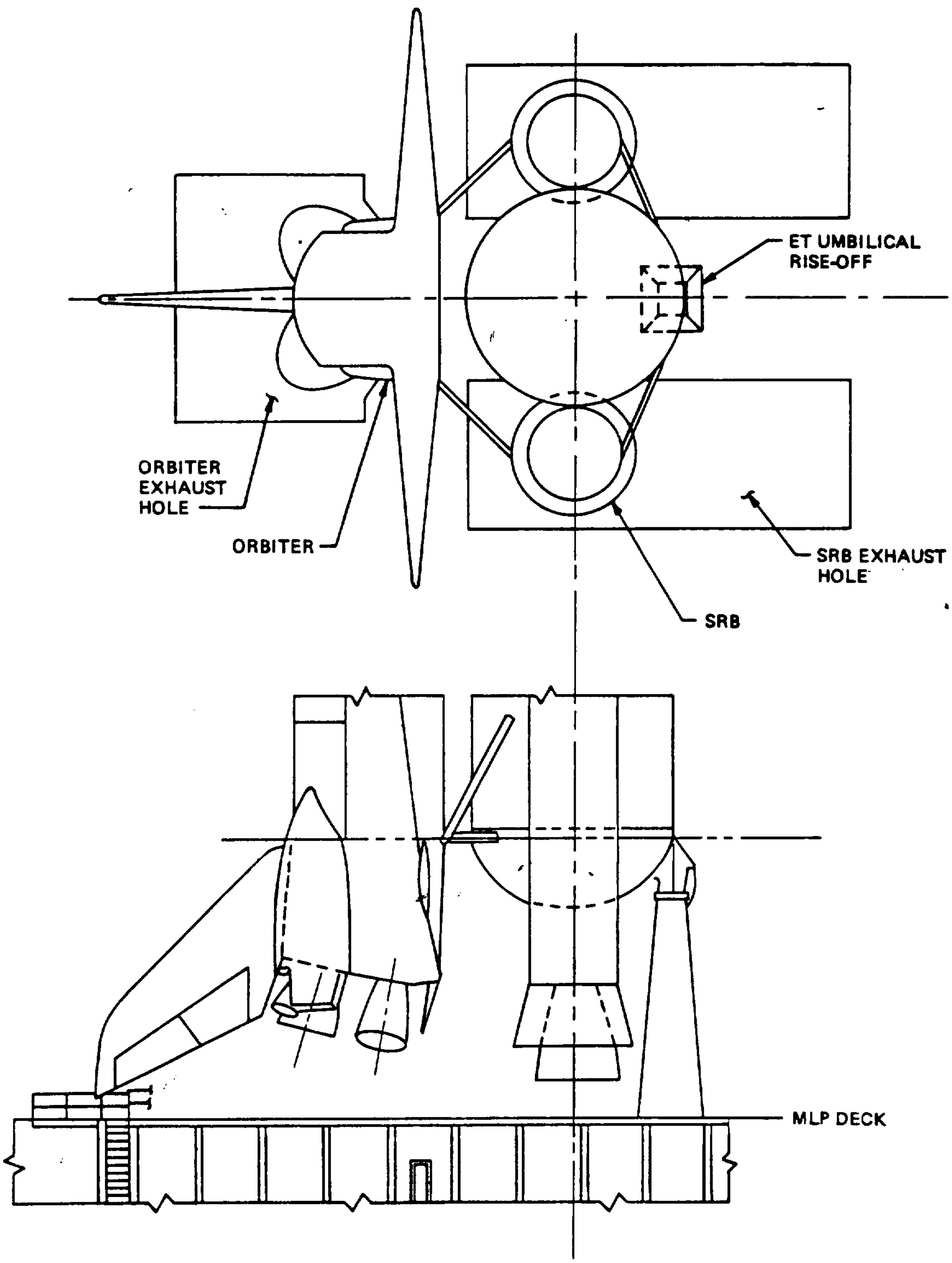

FIGURE 1. CONCEPT I (VENT THROUGH TSM)

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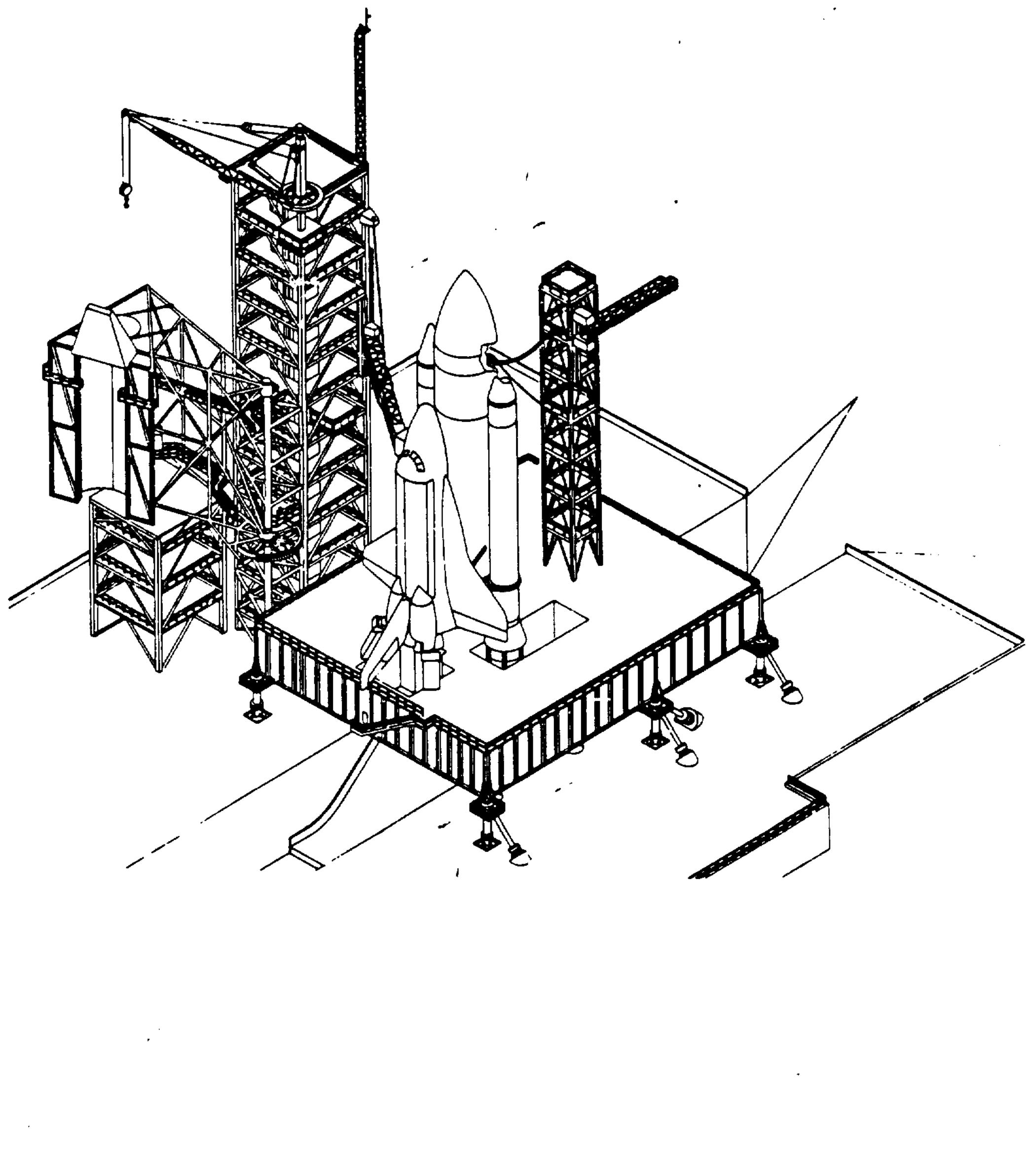


FIGURE 2. GH_2 VENT LINE CONCEPT II (TOWER ON MLP)

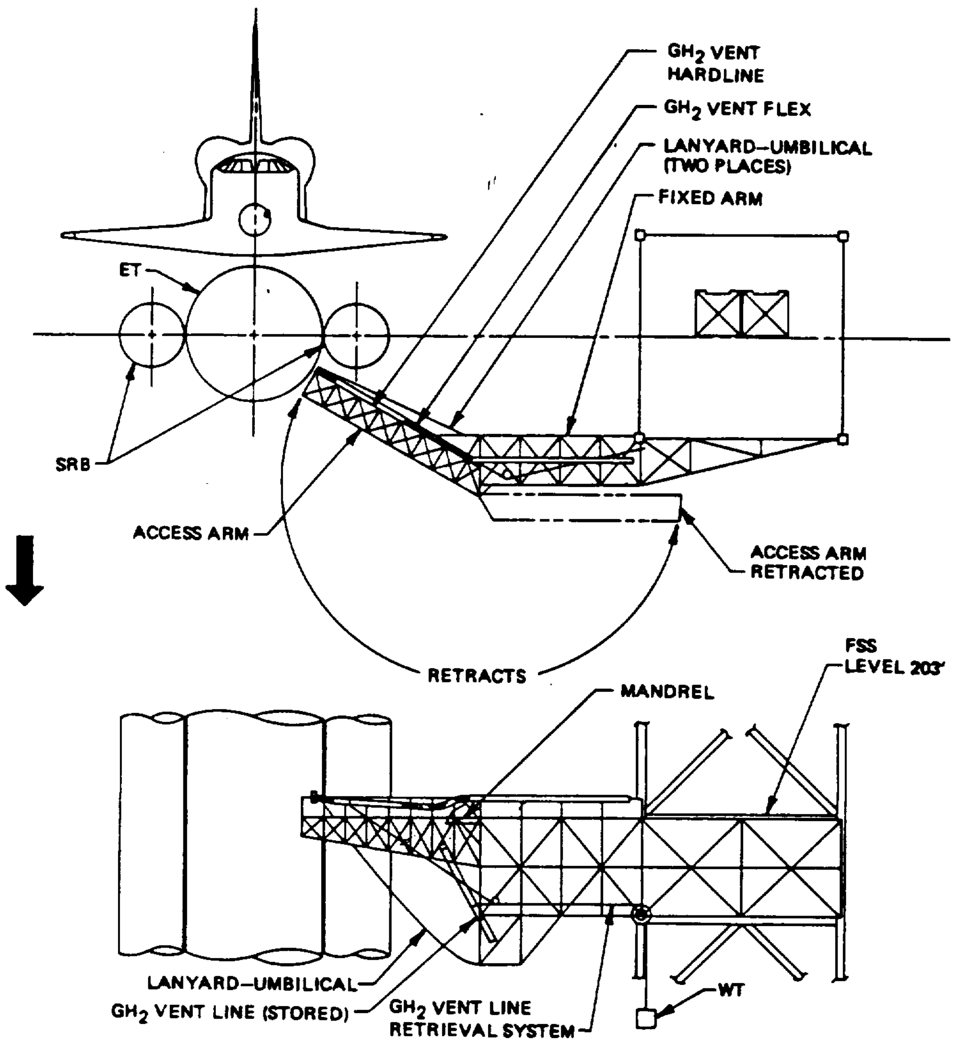


FIGURE 3. GH_2 VENT CONCEPT III (BASE FROM FSS)

allowed to "fall." That change was a dropweight mechanism balanced to pull back the vent line about 24 inches before line drop.

Due to tracking requirements and refined draft analysis, the lanyard-activated hockey stick umbilical disconnect device did not clear the vehicle trajectory in the worst case. It was considered that pyrotechnic bolts fired at T-0 would be a more positive and technically sounder way to release the ground-to-flight umbilical plates, giving the system more time to release and clear the vehicle. After much deliberation and many ministudies, it was decided to use the pyrotechnic bolts as the primary release and the lanyard as a backup. (The lanyard becomes taut only after the vehicle moves up 26 inches.)

Another major system study was cost. The expendable approach was shown to cost about $50,000,000 for the Shuttle launch series of about 450 launches. That cost was excessive. So, a major effort was started to minimize launch damage. The result was to guide the vent arm back under a blast structure, put protective blankets over the flexible line sections, and install a deluge water system to saturate the vent arm during vehicle ascent. This was determined to reduce refurbishment cost to 25% of replacement cost. Indeed, these "fixes" have been good enough to reduce refurbishment cost to essentially zero.

TESTING

Testing was done primarily on a system basis. The total "group system" was tested at KSC's Launch Equipment Test Facility (LETF). The tests did not show any major design deficiencies. Basically, the system was fine tuned with the tests as well as being qualified mechanically. The only design aspect that was questioned aggressively, i.e., the disconnect method, was settled by the tests. The first concept verification testing (CVT) series of the lanyard umbilical disconnect was conducted before the pyrotechnic bolts were selected as the design approach. The second test series system qualification testing employed the bolts and proved the design concept.

PRESENT ASSEMBLY

In summary, the external tank GH_2 vent arm presently provides for more than just venting GH_2. It is an access system for the ET intertank area, and it provides for GH_2 venting, for all ET electrical and pneumatic support subsystems (including all gas purges), and for umbilical plate service in itself. The assembly is best described in two parts: ET vent umbilical system and intertank access arm.

ET HYDROGEN VENT UMBILICAL SYSTEM

This system provides for continuous venting of the Shuttle ET during and after LH_2 loading. It also provides the pneumatic line and electrical cables between the ground systems and the umbilical interface. The umbilical system disconnects at solid rocket booster (SRB) ignition command. The hydrogen vent line then pulls back, drops away, and is secured during vehicle liftoff. Figure 4 depicts the system.

Vent Line Assembly

This assembly consists of two vacuum jacketed flexhoses and one double wall hardline. The aft flexhose makes the connection between the hardline subassembly and the facility vent line interface. The forward flexhose makes the connection between the hardline subassembly and the intertank hydrogen vent umbilical interface.

Structural Platform Extension

The platform extension has four levels floored with steel grating. It provides space for equipment installation and personnel access for service, maintenance, and checkout of the vent line and access arm. A platform is attached to the side of the main platform providing a base for mounting the hinge actuation mechanism of the access arm, the haunch pivot fixture, the withdrawal mechanism, and the deceleration unit.

Haunch Pivot Fixture

This is a structural enclosure mounted on the top level of the fixed platform extension. The haunch pivot fixture contains the pivot links which support the facility end of the vent line and allow the vent line to adjust for vehicle movement and misalignment. The haunch also provides mountings

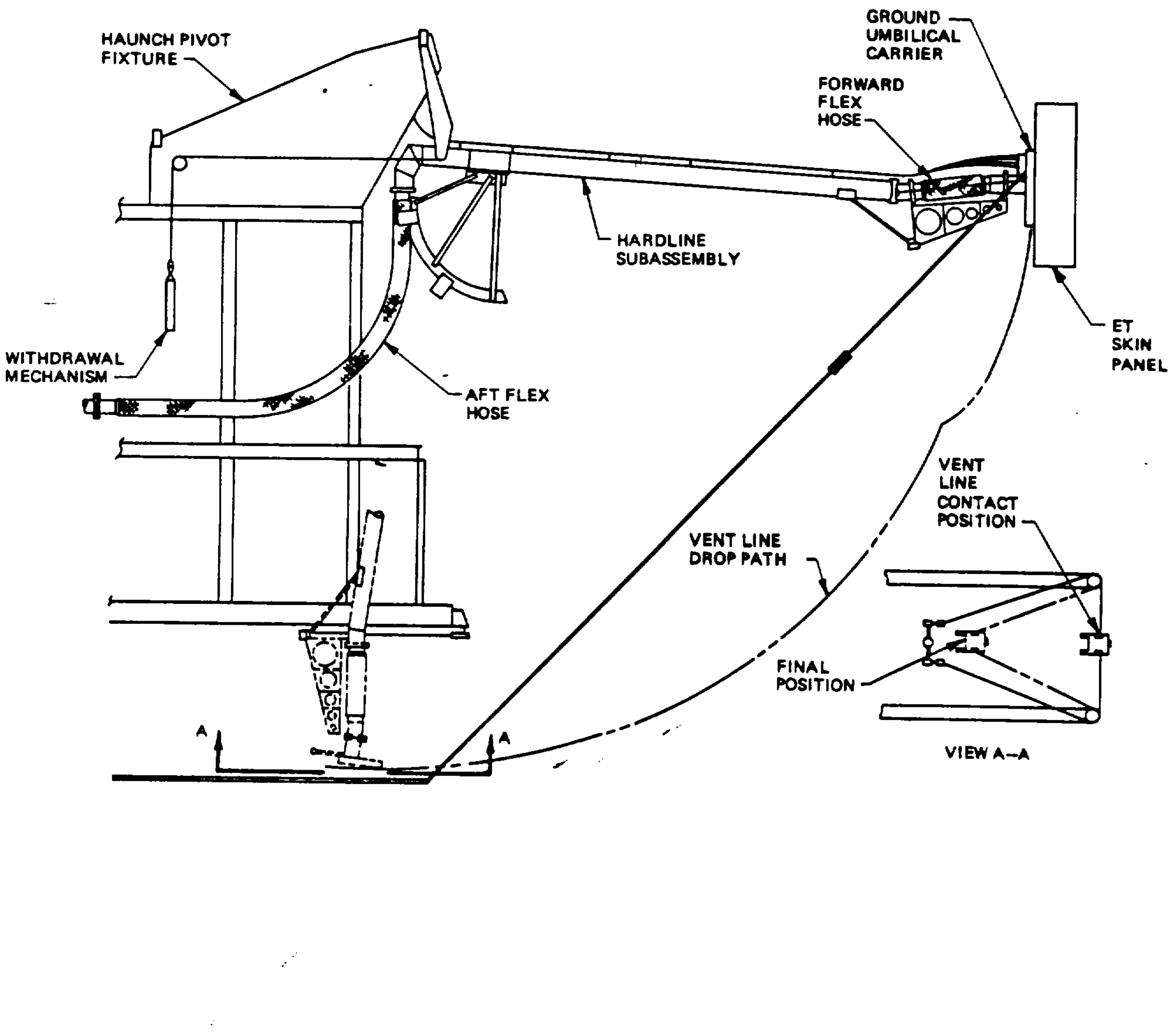


FIGURE 4. ET HYDROGEN VENT UMBILICAL SYSTEM

for the pivot link shock absorbers, latch back mechanism, guide sheaves for the withdrawal weight cables, and bulkhead for pneumatic and electrical interface with the vent line.

Withdrawal Mechanism

This mechanism is located at the back of the haunch fixture. The mechanism has side rails which guide a dropweight. Wire rope cables attached to the weight are routed over the guide sheaves in the rear of the haunch and are connected to the pivot links.

The potential energy of the suspended weight retracts the vent line via the pivot links after umbilical disconnect. The unit utilizes a manually operated winch to raise and reset the dropweight and shock absorbers mounted at the bottom of the side rail frame to decelerate the dropweight at the end of its travel.

Deceleration Unit

The deceleration unit is an arresting device utilizing a tension shock absorber. A cross beam with sheaves is attached to the rod end of the shock absorber. The wire rope arresting cable is routed through sheaves located horizontally and vertically. The routing geometry of the arresting cable allows the falling vent line to be decelerated and stopped approximately 92 inches after contact with the vent line support bracket. A mechanical latching device secures the vent line in the retracted position.

Ground Umbilical Carrier Assembly

The ground umbilical carrier assembly is a structural housing for the ET service line couplings which are mated to the ET umbilical panel. The carrier assembly is attached with a pyrotechnic separator which bolts the carrier assembly to the ET skin panel. The umbilical carrier is released from the ET panel when the pyrotechnic separator receives a triggering signal.

Static Lanyard Mechanism

The static lanyard mechanism is designed to increase the reliability of the ET vent line disconnect function by providing a secondary release system. The static lanyard is attached to each side of the ground umbilical carrier plate and to the structural platform extension. The lanyard is routed through a sheave and pivot arm mechanism, which allows the lanyard to track the vehicle during prelift-off excursions. The pivot arm is weighted to maintain lanyard tension and to minimize lanyard catenary. The mechanism is designed to allow 6 inches of cable feedout prior to the secondary disconnect.

INTERTANK ACCESS ARM

The intertank access arm provides a movable work platform for prelaunch servicing and checkout of the Space Shuttle ET intertank area. It provides the capability of lifting and positioning the vent line, installation with the ground umbilical carrier plate, personnel access for umbilical servicing, personnel access to the intertank tank compartment, AC power, lighting, and environmental control system service. Figure 5 depicts the arm.

Truss Assembly

The top surface of the truss is floored with grating, which serves as a walkway for personnel access. The line handling fixture is attached to the outer end of the truss and provides an air motor driven winch. The winch is used for lifting the vent line into position for installation with the umbilical and supports the vent line until the access arm is retracted.

Hinge Actuating Mechanism

The hinge actuating mechanism is a hydraulic cylinder actuated roller chain and sprocket drive unit. The two hydraulic cylinders are powered by hydraulic fluid supplied from the facility hydraulic system. A manual valve on the control panel controls rotation of the access arm.

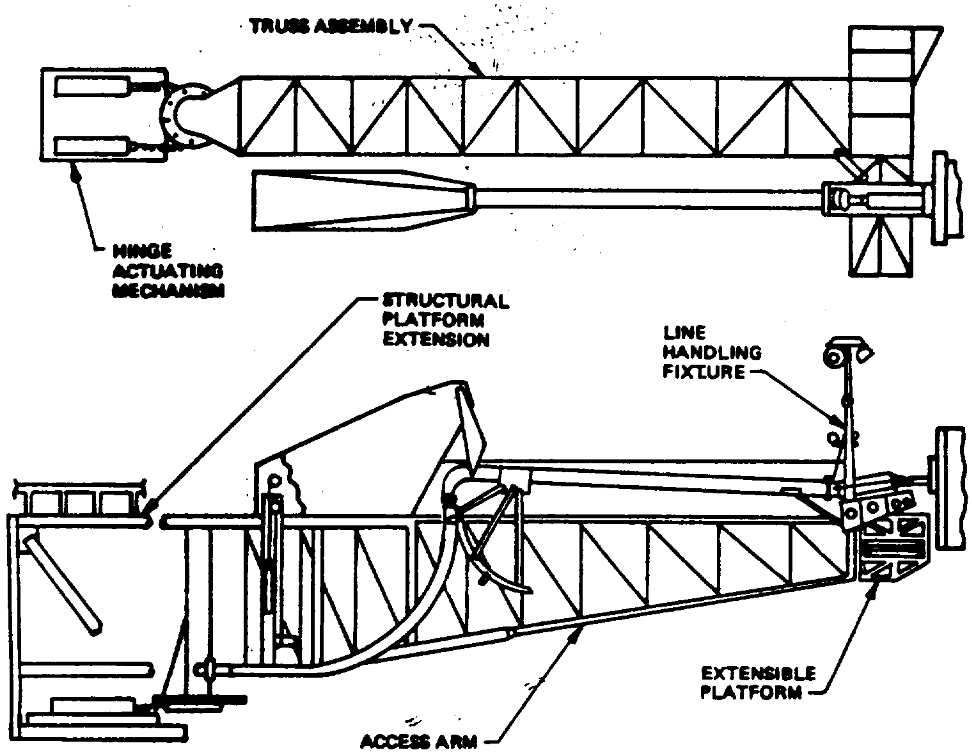


FIGURE 5. INTERTANK ACCESS ARM

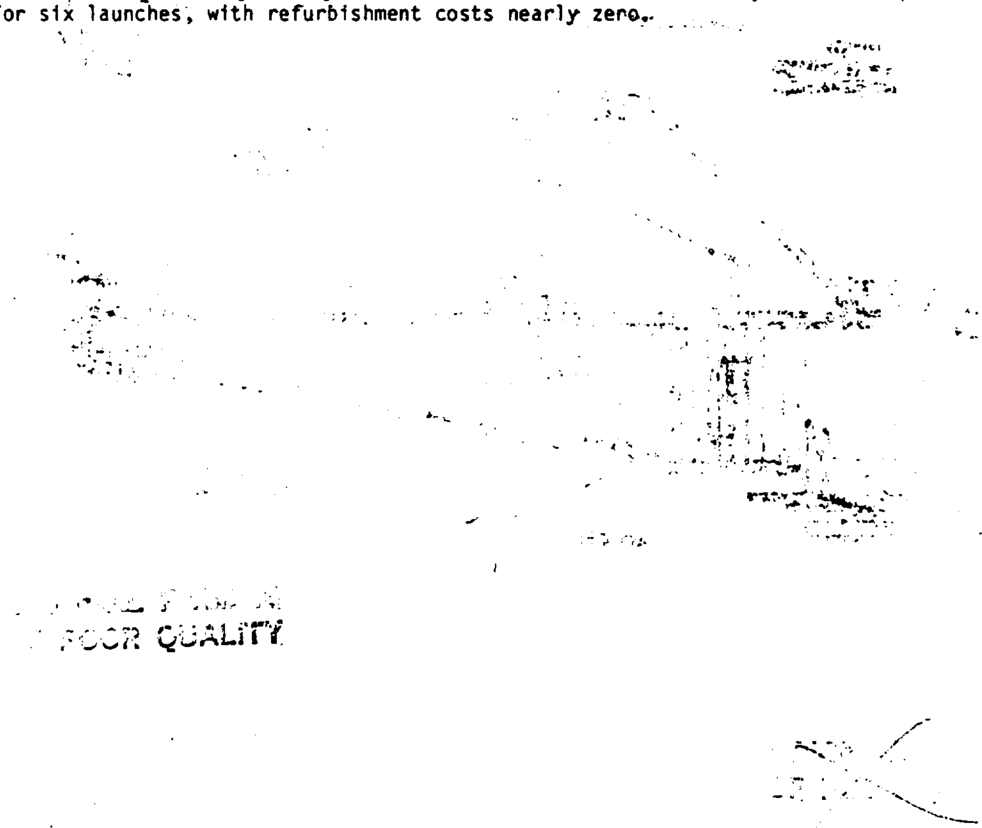
The roller chain is a triple-strand chain which drives a sprocket. The sprocket is attached to the bottom of the hinge assembly, which is supported by a large self-aligning spherical roller bearing. This bearing acts as the lower pivot of the hinge and carries the thrust and radial loads of the access arm. The upper pivot of the hinge assembly has a smaller self-aligning spherical roller bearing, which carries the moment loads of the access arm.

Extensible Platform Assembly

This assembly consists of a fixed platform attached to the outboard end of the truss assembly to provide personnel access to the intertank area. A sliding platform can be extended from the side of the fixed platform, allowing personnel access for servicing the hydrogen vent umbilical, pneumatic service lines, and vent line. The sliding platform is extended or retracted by a handwheel-operated chain and sprocket drive.

SUMMATION

The challenge to provide a safe and reliable means to vent the hydrogen from the Shuttle ET was met through innovative design of a mechanism evolving from changing requirements and employment of basic concepts striving to be both cost effective and highly reliable. The Shuttle ET GH_2 vent arm "system" began as a simple vent line running down the side of the ET and ended as a rather complex centralized servicing system built onto and out from the FSS. Primary design drivers were vehicle weight, vehicle movement on the pad, vehicle launch trajectory, launch damage/refurbishment/replacement costs, physical limitations to ensure no damage to the vehicle at disconnect, and the number of vehicle services other than GH_2 venting through or at the same location. The "system" has operated almost flawlessly for six launches, with refurbishment costs nearly zero.



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