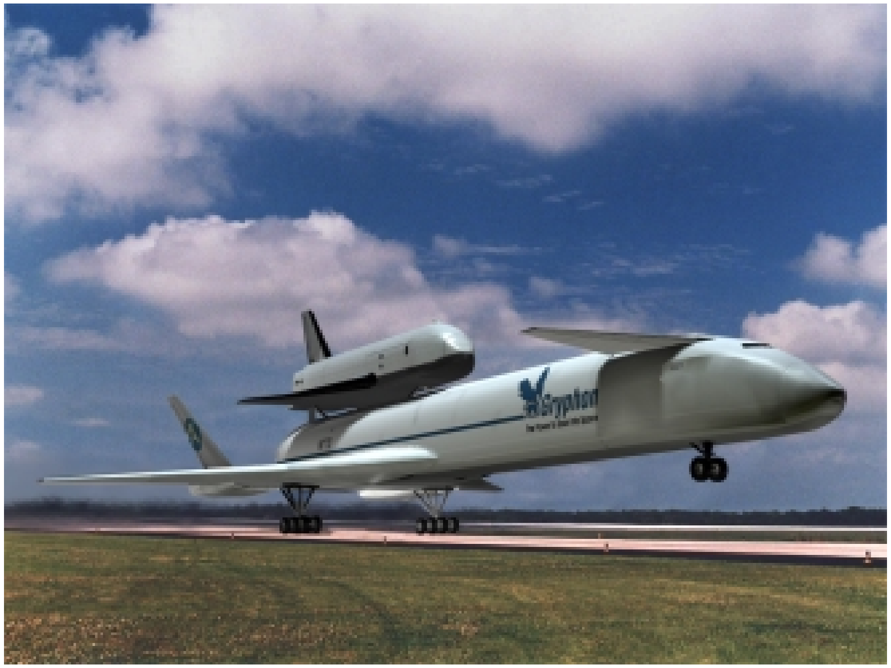
# Airport-to-Orbit, the Economics of Horizontal RLV Systems



**Jason Andrews – President**
**Dana Andrews – Chief Technology Officer**

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# Introduction

- **The Goal of the exercise is to examine the Life Cycle Cost (LCC) of reference Vertical Takeoff / Horizontal Landing (VTHL) and Horizontal Takeoff / Horizontal Landing (HTHL) architectures.**

- **Analyses to date, which represent work in progress, indicate that HTHL concepts have slightly higher DDT&E, but significantly lower recurring costs.**

- **This presentation will explore the unique operating characteristics of HTHL architectures and why they lower a Life Cycle Cost.**

# Assumptions (1 of 2)

- **All vehicles are sized to achieve the following performance:**
  - **50,000 lb of payload / 20,000 lb of cargo to ISS**
  - **15,000 lb of payload to GTO**
  - **15,000 lb of payload to Western Test Range Reference Orbit (Polar)**

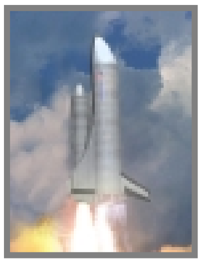
- **All vehicles are assumed to incorporate comparable levels of technology (equivalent TRL values).**

- **Cost Assumptions:**
  - **DDT&E based on three different cost assessments**
  - **Operations Costs based on TRANSCOST 7.0.**

# Assumptions (2 of 2)

- **Vehicle Overview:**
  - **VTHL#1**

    - **Two Stage Bimese (LOX / $LH_2$ for both stages)**
    - **First Stage Dry Mass ~315,000 lb**
    - **Second Stage Dry Mass ~315,000 lb**
  - **VTHL#2**



    - **Two Stage (LOX / RP first stage – LOX / $LH_2$ second stage)**
    - **First Stage Dry Mass ~ 125,000 lb**
    - **Second Stage Dry Mass ~ 2x 80,000 lb**
  - **HTHL#1**

    - **Two Stage (LOX / $LH_2$ for both stages)**
    - **First Stage Dry Mass ~ 600,000 lb**
    - **Second Stage Dry Mass ~ 115,000 lb**

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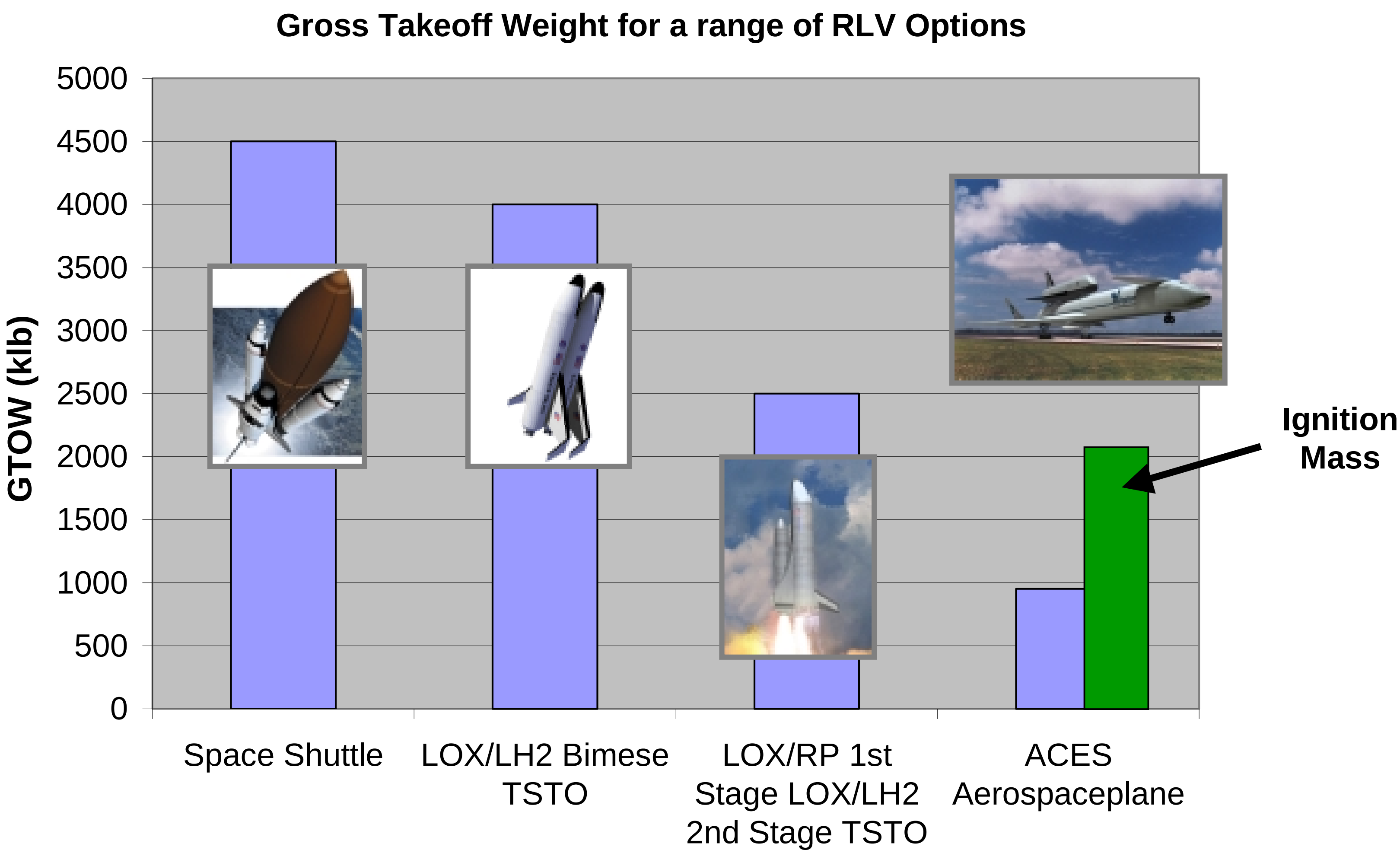
# GTOW of Reference Architectures versus Shuttle




**VTHL#1** **VTHL#2** **HTHL#1**

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# Elements of Life Cycle Cost

- **Life Cycle Cost is the sum of recurring and non-recurring costs.**

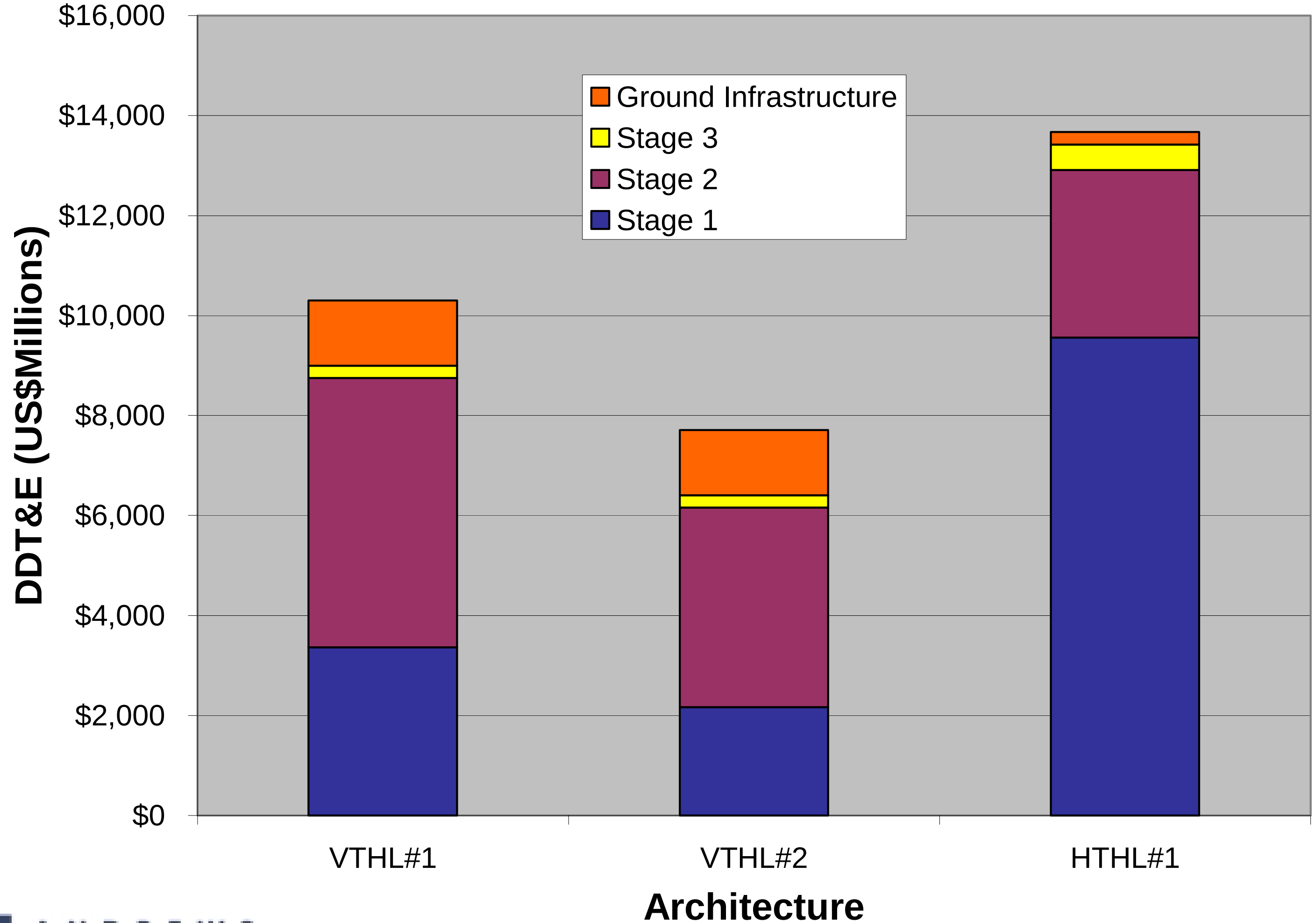
| Type of Cost | Cost Elements |
|---|---|
| Non-Recurring | DDT&E |
| Recurring | Amortization of Production |
| | Expended Hardware |
| | Spares / Refurbishment |
| | Pre-launch Ground Operations |
| | Propellant |
| | Launch Infrastructure Support |
| | Insurance / Abort / LOV Charges |
| | Indirect Operating Costs |

**Note: For more information see TRANSCOST 7.0**

- **Historically, Government programs are driven by up-front Non-Recurring Costs while commercial development programs (e.g. Commercial Airplanes) are driven by Life Cycle Cost.**

# Development Cost

- **A review of development cost provides one assessment.**

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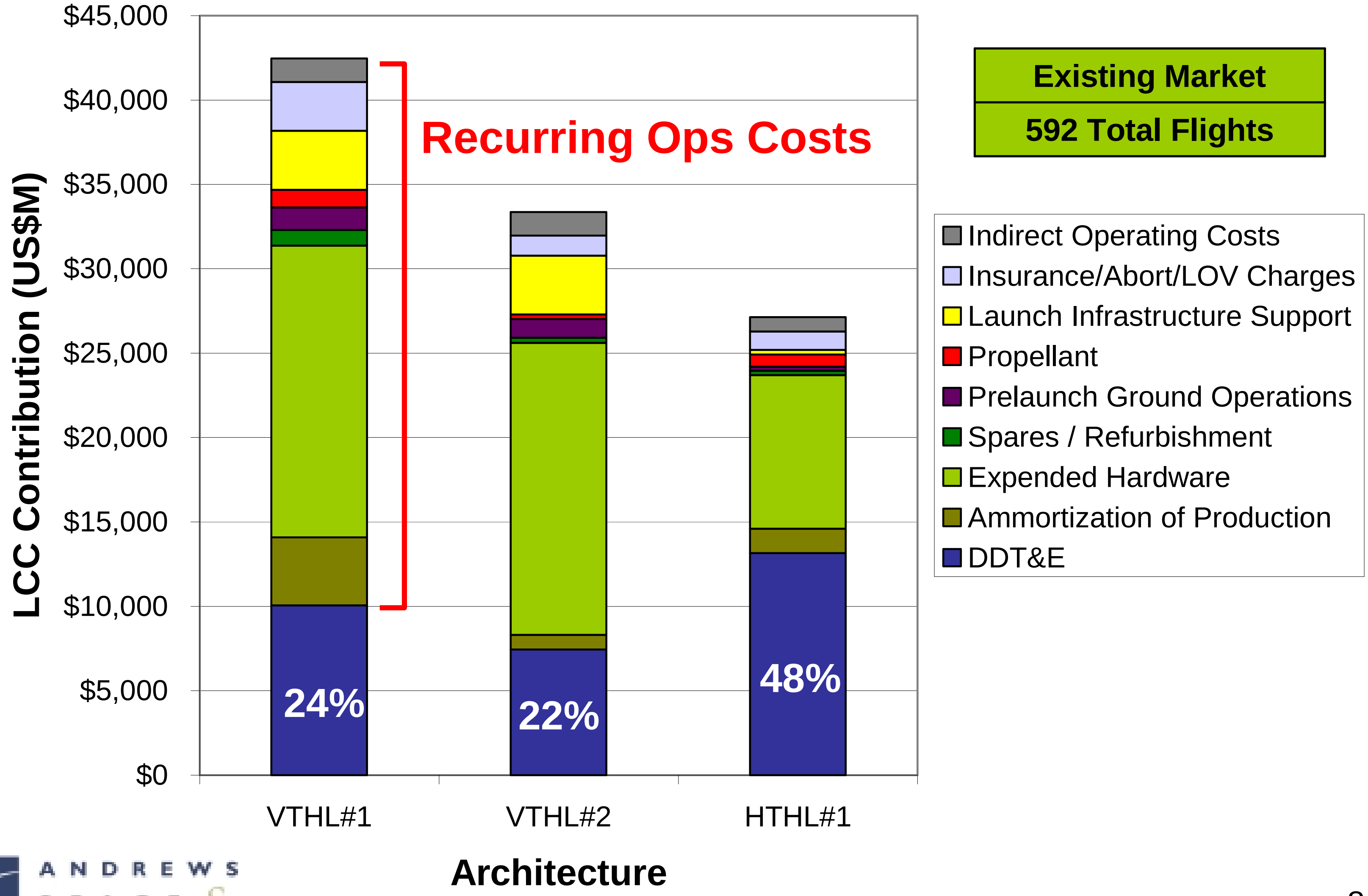
# LCC Comparison for Existing Markets

- **While examination of Life Cycle Cost reveals another….**

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# Cost Advantages of HTHL Systems

- **HTHL Systems have specific advantages that reduce their overall Life Cycle Cost:**
  - **Safety:**
    **HTHL systems can position their launch ignition point to minimize or eliminate "Dead Zones" during ascent. This combined with reduced thrust requirements enables the use of safer Split-Expander Cycle engine to**
    - **Significantly improve overall system safety**
    - **Reduce Loss of Vehicle Self-Insurance Costs**
  - **Reduced Launch Infrastructure:**
    - **HTHL systems can operate from a single operating hub and address all azimuth capability.**
    - **Because ignition occurs at altitude there is no need for (2) launch pads, transporters, and erectors. This reduces launch infrastructure further and saves on maintenance costs.**

# Safety

- **Rocket Propulsion System failure tolerance, enabled by HTHL architectures, significantly improves system safety.  This is because HTHL architectures can locate launch corridors to eliminate RLV “Dead Zones” during ascent (areas where RTLS or other vehicle recovery aborts are not an options).**
- **Recovering from rocket propulsion failures also relaxes rocket engine verification program requirements.**

| | VTHL TSTO | | HTHL TSTO | |
|---|---|---|---|---|
| EXAMPLE: KSC Operating Base | Bimese Cobra | Bimes SSME | ACES Cobra / RLX | Units |
| Number of engines on stg1 | **5** | **5** | **2** | Engines |
| 1st Stg burn time | **150** | **155** | **150** | Seconds |
| Dead zone for loss of one engine | **0** | **0** | **0** | Seconds |
| Dead zone for loss of two or more engines | **40** | **40** | **0** | Seconds |
| Number of engines on stg2 | **5** | **5** | **2** | Engines |
| 2nd Stg Burn Time (Parallel Burn) | **400** | **400** | **400** | Seconds |
| Dead zone for loss of one engine | **50** | **50** | **0** | Seconds |
| Dead zone for loss of two or more engines | **150** | **150** | **180** | Seconds |
| 1st Stg Engine Contained Shutdown Rate | **985.5** | **1042** | **985.5** | Probably per 1,000,000 Cycles |
| 1st Stg Engine Uncontained Shutdown Rate | **196.3** | **258** | **196.3** | Probably per 1,000,000 Cycles |
| 1st Stg Engine Shutdown w/ Collateral Damage | **39.3** | **258** | **39.3** | Probably per 1,000,000 Cycles |
| 2nd Stg Engine Contained Shutdown Rate | **985.5** | **1042** | **950.9** | Probably per 1,000,000 Cycles |
| 2nd Stg Engine Uncontained Shutdown Rate | **196.3** | **258** | **139.9** | Probably per 1,000,000 Cycles |
| 2nd Stg Engine Shutdown w/ Collateral Damage | **39.3** | **258** | **1.4** | Probably per 1,000,000 Cycles |
| Nonengine Catastrophic Failure Rate | **10** | **10** | **10** | Probably per 1,000,000 Cycles |
| **Mean Flights Between Loss of Vehicle** | **3,045** | **750** | **20,154** | |

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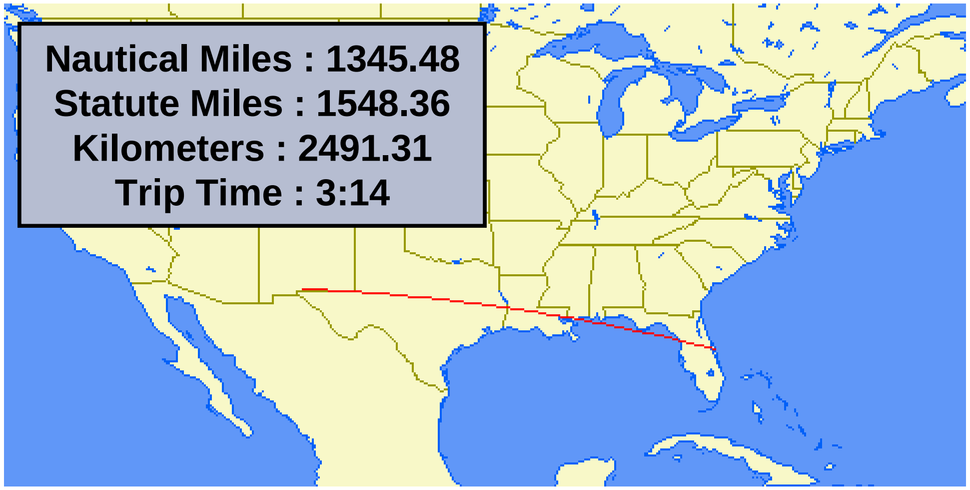
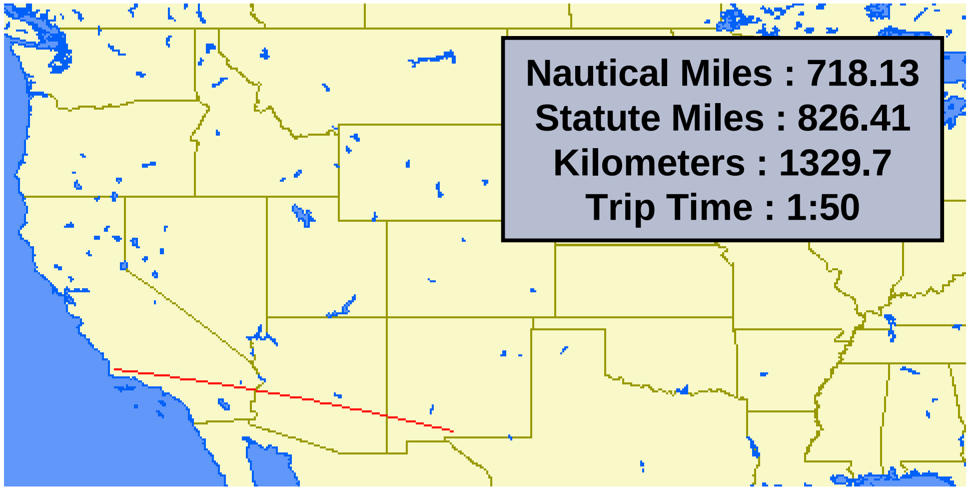
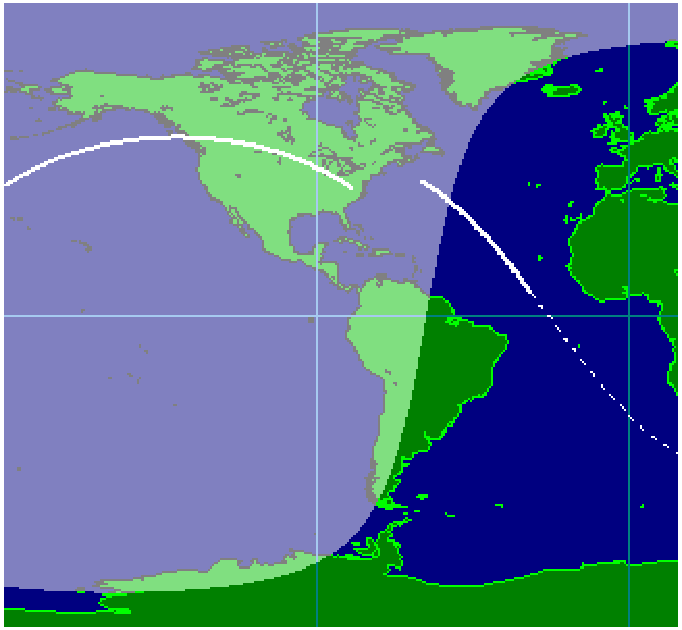
# Launch Availability / All Azimuth Capability

ETR Operations (Incl. 28 to 60)




WTR Operations (Incl. 60+)



**HTHL can operate from multiple locations to avoid weather and "cruise" to required launch location to ensure multiple direct launch / rendezvous opportunities per day.**

**Ground launch systems are constrained by local weather and limited direct rendezvous opportunities.**

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# Launch Infrastructure

- **To address all-azimuths, VTHL systems require two dedicated launch infrastructures (ranges) while a HTHL system can be located at a single existing airport.**
  - **VTHL Systems: Non Recurring: $1.3B**
  - **HTHL Systems: Non Recurring: $250M**

| Attribute | VTHL | HTHL | Non-Recurring | Amortization Factor |
|---|---|---|---|---|
| Vehicle Integration Facility | 2 | 1 | $200M | 3% |
| Payload Processing Facility | 2 | 1 | $40M | 3% |
| RLV Operations Center | 1 | 1 | $10M | 3% |
| Runway | existing | existing | N/A | |
| Launch Pad | 2 | | $200M | 10% |
| Erector | 2 | | $200M | 10% |

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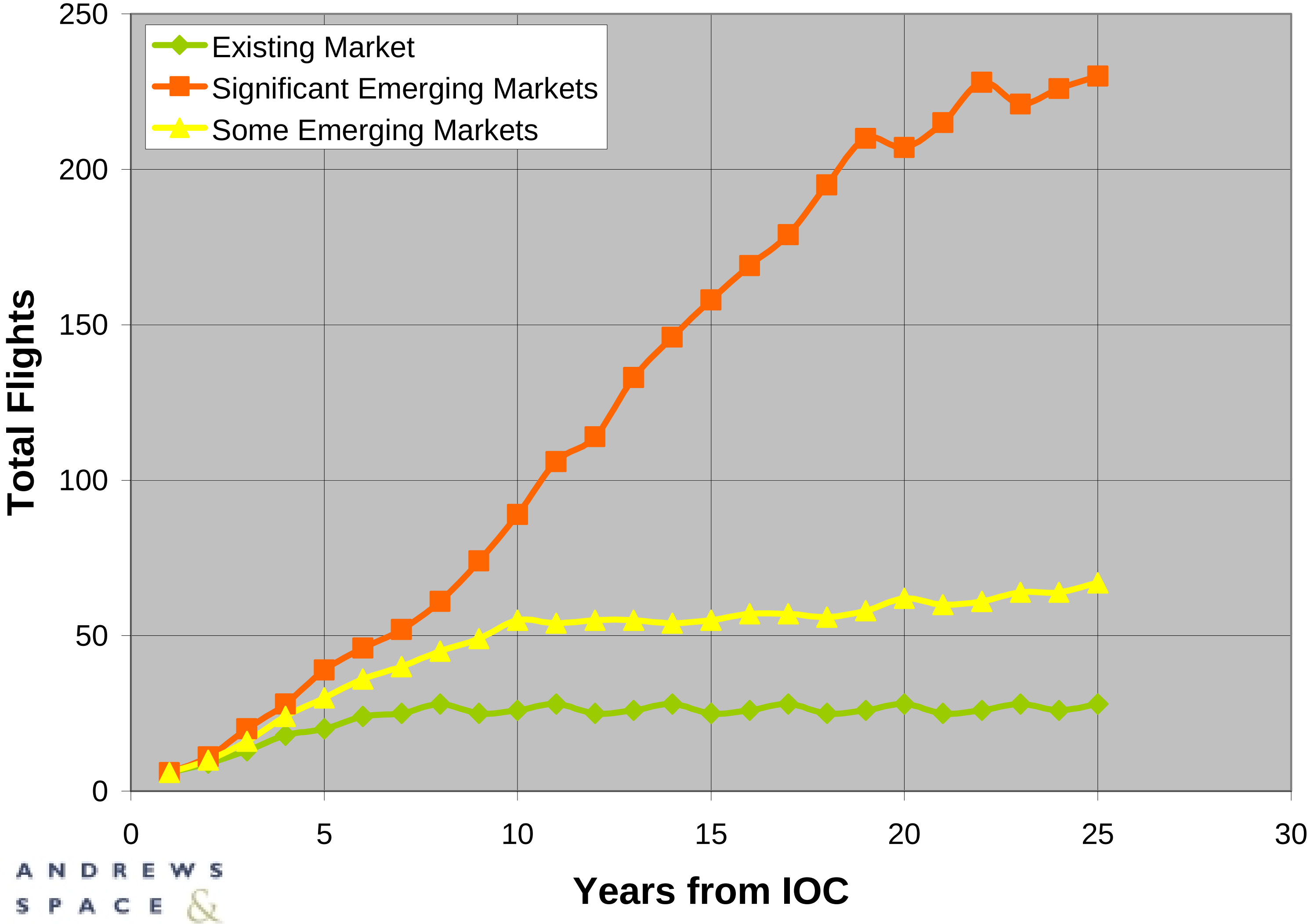
# Mission Scenarios

- **Examined three different mission scenarios to gauge the relationship between Development Cost and Life Cycle Cost.**

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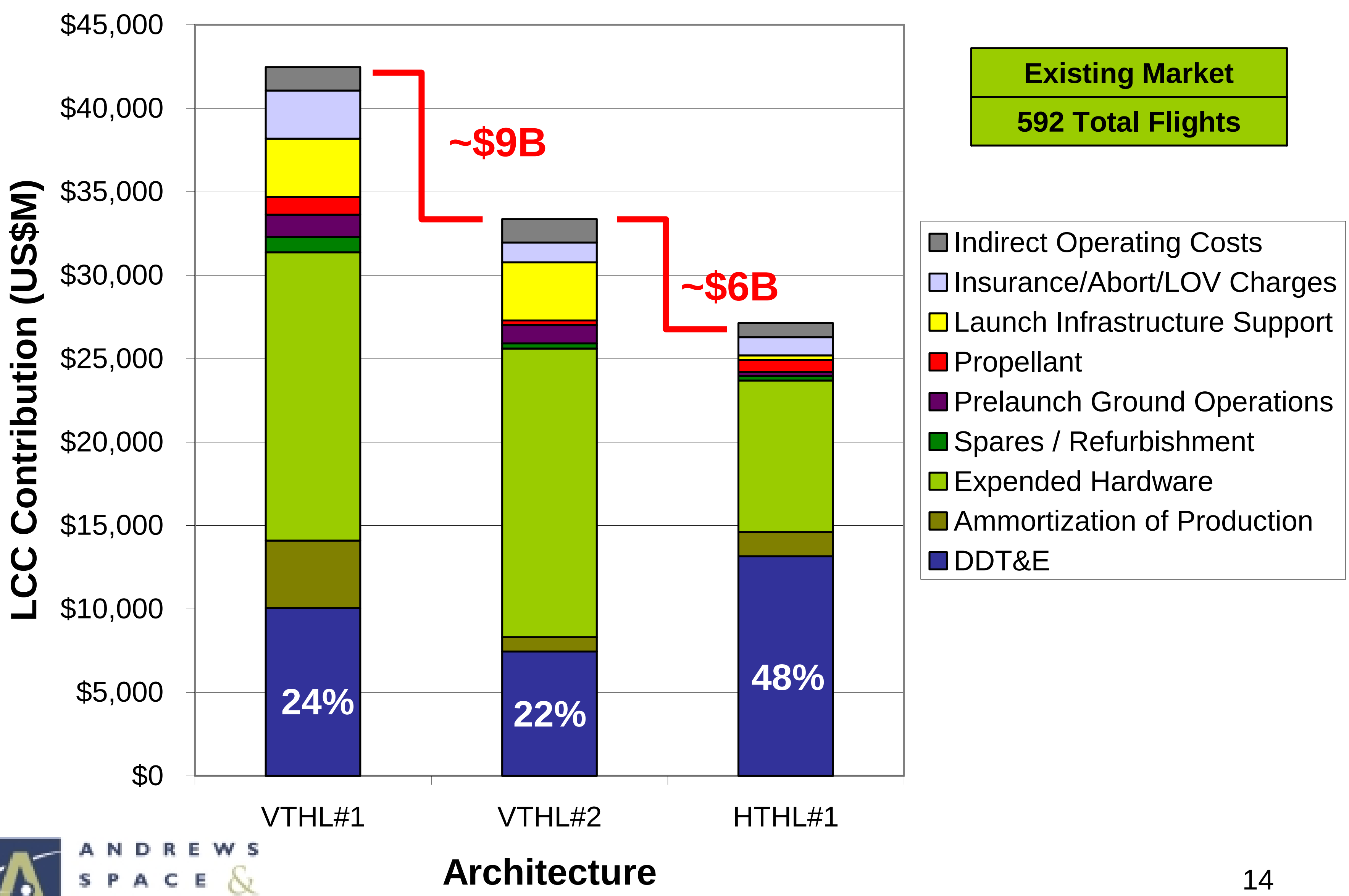
# LCC Comparison for Existing Markets

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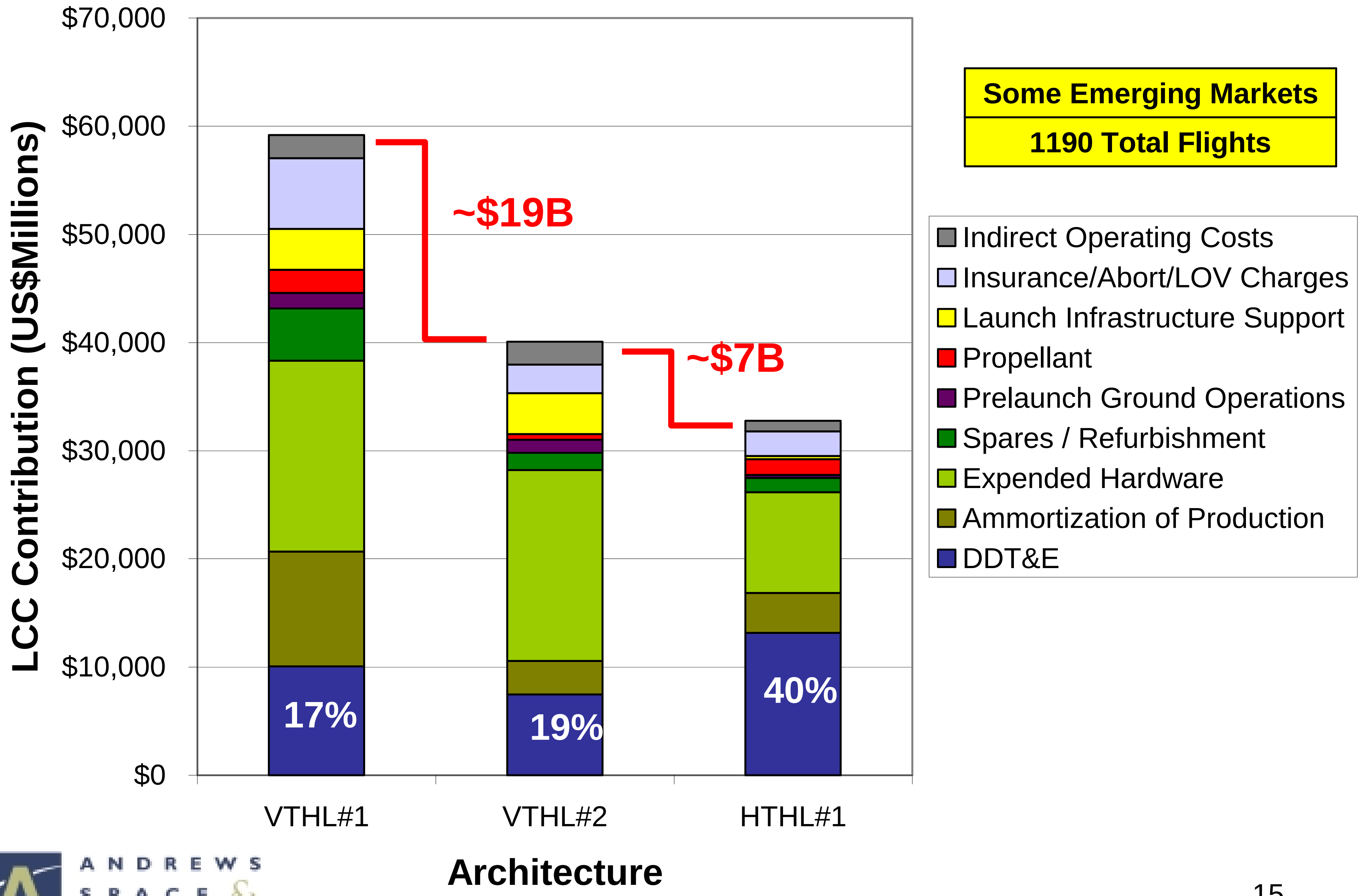
# LCC Comparison w/ Some Emerging Markets

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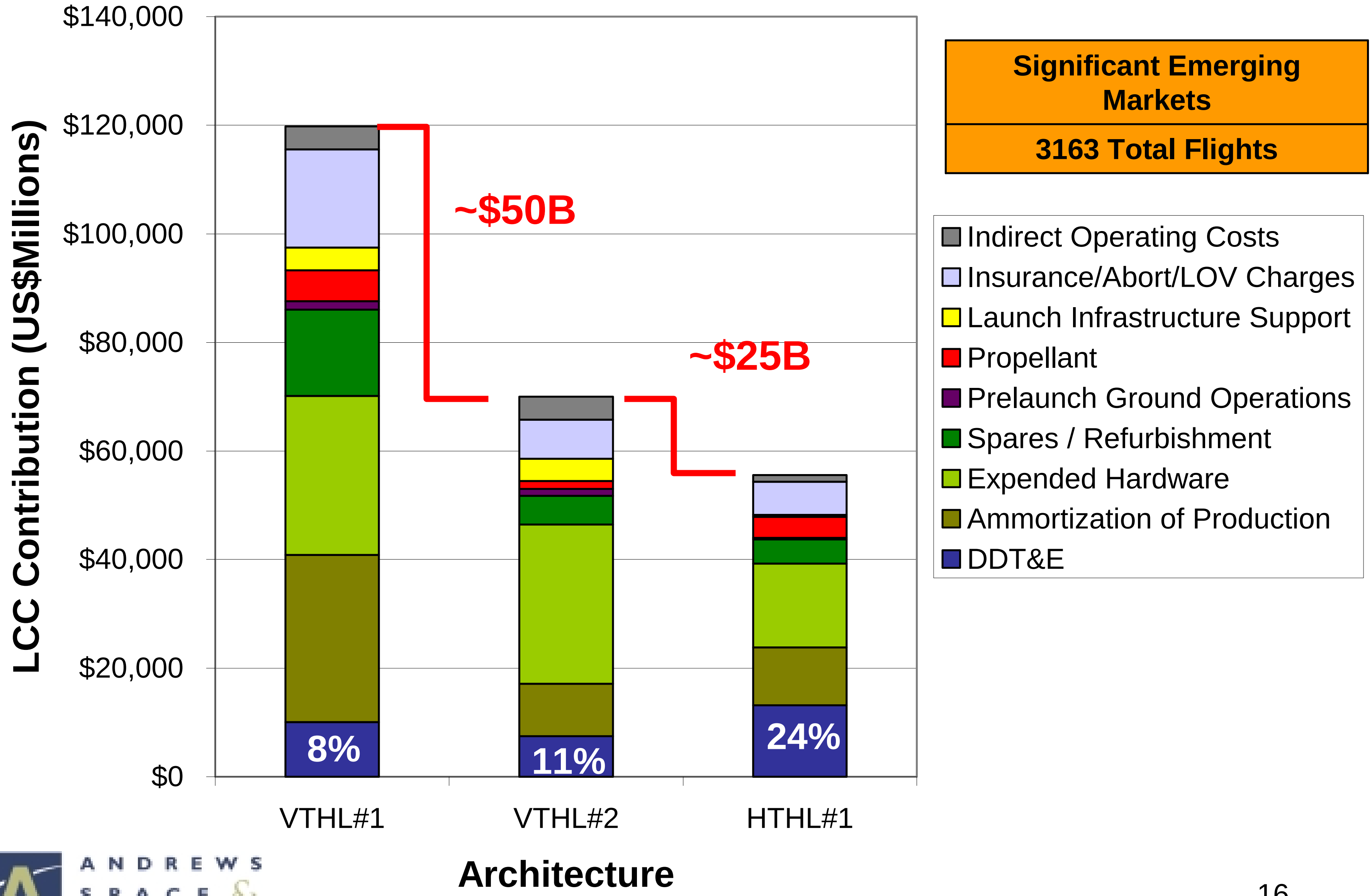
# LCC Comparison w/ Large Emerging Markets

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# Market Addressability

- For a HTHL Next Generation RLV, ability to:
  - Have multiple launch opportunities per day
  - Have significantly improved safety
  - Simplify launch / passenger loading operations

…which increases the addressable markets.

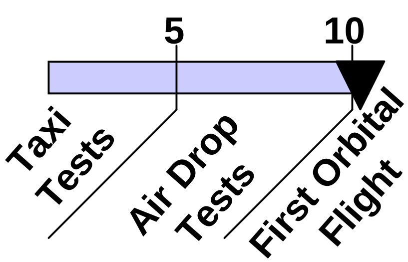
| VTHL & HTHL Markets | HTHL Unique Markets |
| --- | --- |
| ISS Logistics | Large Scale Tourism (>10 people/flt) |
| Spacecraft Delivery | Entertainment |
| Small Scale Tourism (<10 people/flt) | |
| Satellite Servicing | |
| LEO Business Park | |

# Flight Testing / Certification Issues

- **HTHL can use aircraft-type flight testing program with incremental risk build-up while VTHL must commit to "all up" orbital flights early in the test program. This approach (e.g. B777 versus Boeing Delta III) significantly effects to programmatic risk.**

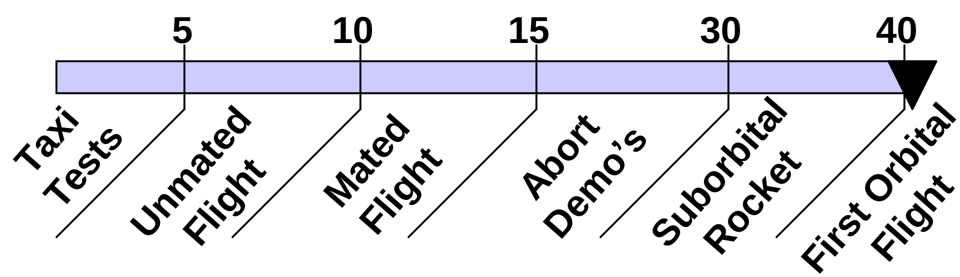
## VTHL

- **Shuttle Type Test Program**
  - **Air Drop small orbiters**
  - **First powered flight "all up" to orbit**




## HTHL

- **Aircraft Type Test Program**
  - **Phased Approach**
  - **Taxi Tests – Unmated Flight – (…) - Orbital**

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# Summary

- **Initial analyses and trends indicate that HTHL is superior to VTHL from an economic standpoint.**

- **Horizontal Takeoff and Landing:**
  - **Reduces Life Cycle Cost to NASA**
  - **Increases RLV safety**
  - **Reduces Ground Based Infrastructure**
  - **Increases Commercial Viability through:**
    - **Increased number of addressable markets**
    - **Lower per flight operating costs**
    - **Has the ability to incubate new markets and improve US Economic Impact**
  - **Reduces program risk through increased safety and Low Risk flight test program**

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