A very large asymmetric (22 m x 13 m x 7 m) composite payload fairing was developed for launching payloads of unconventional geometry and size on the Atlas V Heavy Lift Vehicle. Currently no launch system exists which can accommodate these payloads without requiring a redesign of the launch vehicle and/or integration facility. The asymmetric design was tailored to accommodate very large payloads while maintaining structural requirements and control authority limits of the launch vehicle as it currently stands. An optimal design was achieved through the use of an innovative Computational Fluid Dynamics (CFD)-based geometric optimization, composite structural tailoring, and novel manufacturing methods. The design was validated through correlation with subscale wind tunnel testing and extremely close agreement between the analysis and test was achieved. The final design resulted in a composite sandwich structure that meets or exceeds strength, buckling, flutter, thermal, and acoustic requirements and does not require significant modifications to existing launch pad integration facilities. The geometry, methods, and processes demonstrated during this effort have wider applicability to the whole range of launch vehicle sizes and can increase the payload capabilities of each by offering fairings which are tailored specifically to existing control capability and payloads of nonstandard geometry.