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Acta Astronautica 58 (2006) 209–221
ACTA ASTRONAUTICA
www.elsevier.com/locate/actaastro

Long-term/strategic scenario for reusable booster stages

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Received 21 June 2004; received in revised form 31 August 2005; accepted 28 September 2005

Abstract

This paper describes the final design status of a partially reusable space transportation system which has been under study for five years within the German future launcher technology research program ASTRA. It consists of dual booster stages, which are attached to an advanced expendable core. The design of the reference liquid fly-back boosters (LFBB) is focused on LOX/LH2 propellant and a future advanced gas-generator cycle rocket motor. The preliminary design study was performed in close cooperation between DLR and the German space industry. The paper's first part describes recent progress in the design of this reusable booster stage.

The second part of the paper assesses a long-term, strategic scenario of the reusable stage's operation. The general idea is the gradual evolution of the above mentioned basic fly-back booster vehicle into three space transportation systems performing different tasks: Reusable First Stage for a small launcher application, successive development to a fully reusable TSTO, and booster for a super-heavy-lift rocket to support an ambitious space flight program like manned Mars missions. The assessment addresses questions of technical sanity, preliminary sizing and performance issues and, where applicable, examines alternative options.

1. Introduction

A reusable booster stage dedicated for near-term application with an existing expendable core is under investigation within the system studies of the German future launcher technology research program ASTRA. To date, analysis shows that such a winged fly-back booster in connection with the unchanged Ariane 5 expendable core stage is technically feasible and is a competitor to other reusable and advanced expendable launchers.

Realizing the fact that a single launch system application alone might not be sufficient to justify the development of a reusable stage, the options for continuous operation of such stages or of their derivatives in a timeframe of at least 50 yr should be investigated. A major constraint for such a roadmap is that it is only viable if a flexible operational scenario exists.

The basic design philosophy of the reusable booster is to choose a robust vehicle which gives a relatively high degree of confidence to achieve the promised performance and cost estimations. In the second part of the research study 'lessons learned' from the first phase and previous investigations (e.g. Refs. [1] and [2]) are integrated. In as far as it is possible the applicability of existing and already qualified parts should be assessed for integration in the booster stage.

2. Proposed semi-reusable launch vehicle in combination with Ariane 5

The examined partially reusable space transportation system consists of dual booster stages which are

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doi:10.1016/j.actaastro.2005.09.012

Nomenclature

D	drag (N)
L	lift (N)
M	Mach number (—)
T	thrust (N)
W	weight (N)
l	body length (m)
m	mass (kg)
sfc	specific fuel consumption (g/kNs)
q	dynamic pressure (Pa)
v	velocity (m/s)
α	angle of attack (—)
γ	flight path angle (—)
δ	deflection angle (—)
ε	expansion ratio (—)
η	control surface deflection angle (—)

Subscripts, abbreviations

AVUM	attitude & vernier upper module (of Vega)
CAD	computer aided design
CFRP	carbon fiber reinforced polymer
EAP	etage d'accélération à poudre (solid booster stage of Ariane 5)
EPC	etage principal cryotechnique (main cryogenic stage of Ariane 5)
ESC-B	etage supérieur cryotechnique (cryogenic upper stage of Ariane 5)
ET	external tank
EUS	expendable upper stage
FEI	flexible external insulation
FEM	finite element method
GLOW	gross lift-off mass
GTO	geostationary transfer orbit
H-xyz	cryogenic stage with *xyz* tons of propellant
H2K	hypersonic wind tunnel (at DLR Cologne)
JAVE	jupe avant equipée (forward skirt of Ariane 5)
LEO	low earth orbit
LFBB	liquid fly-back booster
MECO	main engine cut off
RCS	reaction control system
RFS	reusable first stage
RLV	reusable launch vehicle
SHLL	super heavy lift launcher
SRM	solid rocket motor
SSO	solar synchronous orbit
TMK	trisonic test section (at DLR Cologne)
TSTO	two stage to orbit
TVC	thrust vector control
cog	center of gravity
sep	separation
s/l	sea-level

attached to the expendable Ariane 5 core stage (EPC) at an upgraded future technology level. The EPC stage, containing about 185,000 kg of sub-cooled propellants, is assumed to be powered by a single advanced derivative of the Vulcain engine with increased vacuum thrust. A new cryogenic upper stage (ESC-B) should include a new advanced expander cycle motor of 180 kN class (VINCI) at the end of the decade.

Two symmetrically attached reusable boosters, replacing the solid rocket motors EAP in use today, accelerate the expendable Ariane 5 core stage up to separation (Fig. 1). All the obtained data of the investigations presented here are easily transferable to launcher configurations including other expendable core stages of similar size. The interest in reusable booster stages is not restricted to combinations with Ariane 5 derivatives.

2.1. LFBB geometry data and lay-out

The reusable booster stage propulsion is based on the same advanced version of the EPC's engine, but employs an adapted nozzle with reduced expansion ratio. Three engines are installed in a circular arrangement at the aft of each vehicle. The total length of the latest LFBB variant "Y-9" is almost 41 m. A fuselage and outer tank diameter of 5.45 m is selected so as to achieve a high commonality with Ariane's main cryogenic EPC stage.

Three air-breathing engines, for fly-back, are installed in the vehicle's nose section (see Fig. 2), which also houses the RCS and the front landing gear. The nose is of ellipsoidal shape with a length of 6.7 m. The nose section is followed by an annular attachment structure. The structure for canard mounting and actuation is provided at the center of this attachment ring. The cylindrical tank is integral and has the same diameter as the EPC core stage as well as similar lay-out but is shorter in length. This geometry constraint might reduce manufacturing costs if realized, and enables to better compare expendable with reusable structures within this investigation. LOX is stored in the upper portion of the tank and is separated by a common bulkhead from