Journal of Loss Prevention in the Process Industries 41 (2016) 382–398

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Estimation of explosion loading on small and medium sized equipment from CFD simulations

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ARTICLE INFO

Article history:
Received 16 May 2015
Received in revised form
5 December 2015
Accepted 6 December 2015
Available online 22 December 2015

Keywords:
CFD explosion modeling
FLACS
Explosion loading
Drag
Pressure

ABSTRACT

Explosion studies for design purposes are performed on daily basis among safety consultants all over the world. For oil and gas facilities offshore, and often onshore, the computational fluid dynamics (CFD) tool FLACS is usually applied, while others use simple blast curve formulations, like the TNO-Multi Energy Method. The purpose of the explosion studies is usually to give guidance on required design strength of equipment, piping, blast walls or buildings during design, or to verify a chosen design. One key element is to translate the results from an explosion simulation into actual forces on equipment. For CFD studies loads on large objects can usually be well estimated by reporting differential pressures across the objects. For objects with key dimensions less than 2–3 grid cells (typically ~1m-2m), and in particular less than one grid cell, this approach is not feasible. Industry guidance exists on how to estimate explosion loads on piping and smaller equipment using a drag force formulation. This study demonstrates how the current guidance may lead to too low predicted explosion loads onto equipment. More precise methods for load prediction onto piping, small and medium sized equipment are thereafter proposed and evaluated.

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1. Introduction

The purpose of an explosion study is usually to give guidance on required design strength or to confirm actual design for a facility or nearby structures. Explosion studies are performed in a number of ways. For offshore oil and gas installations a common approach (NORSOK Z-013, 2010, and ISO, 19901-3, 2010) will be to demonstrate that the installation can survive all explosion accidents with a return frequency higher than 10^{-4}/year, and to demonstrate this several hundred CFD dispersion and explosion calculations are usually performed (Hansen et al., 1999 and Hansen et al., 2013). Some safety standards (e.g. API RP-752, 2009) require that buildings shall be designed to withstand a credible worst-case explosion, and simple blast curves estimating free-field blast strength (pressure, duration and impulse) as function of distance are expected used to estimate the loads.

Regardless of the method and approach used, there is a need to estimate the explosion loads onto piping, equipment, walls and structures, and the conclusions from an explosion study will be influenced by the way this is done. In a transient flow field during an explosion pressure differences will build up around objects, and by integrating the pressure over the surface of an object, a good estimate of the explosion loading (forces onto the object) can be obtained. To estimate the explosion load based on differential pressures is thus the approach recommended for objects which are properly resolved on the simulation grid in a CFD-simulation, like blast walls, large objects and decks. Good explosion load estimates from differential pressures can be expected for objects at least 2–3 grid cells across, while typical grid cell sizes for explosion studies may be 0.5 m–1.0 m. For smaller objects estimates of differential pressures will be less accurate, and for objects with diameter less than 1.0–1.5 grid cells, it may not even be possible to extract a differential pressure from the simulation. For such objects the load may be estimated from a general drag formula (Sand, 1999):

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http://dx.doi.org/10.1016/j.jlp.2015.12.004
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Nomenclature

API	American Petroleum Institute (www.api.com)
BFETS	Blast and Fire Engineering for Topside Structures (Joint Industry Project, 1990–1998)
CFD	Computational Fluid Dynamics
DDT	Deflagration to detonation transition
DLM	Direction Load Measurement
FABIG	Fire and Blast Information Group (www.fabig.com)
FLACS	CFD-software for explosion modeling (www.gexcon.com)
FLNG	Floating Liquified Natural Gas vessel
FPSO	Floating Production, Storage and Offloading vessel
HSE	UK Health and Safety Executive (www.hse.gov.uk)
ISO	International Organiazation for Standardization (www.iso.org)
NORSOK	Standards to ensure competiveness on the Norwegian Continental Shelf (www.standard.no)
PDF	Pressure distribution function

prioritization.

Load estimates for pipes and smaller equipment are usually only considering the form drag, which is the first term of (1). This is the only component mentioned in (BFETS Interim Guidance Notes, 1992), while in (FABIG TN-08) all terms of (1) are mentioned, but it is suggested that form drag using conservative drag coefficients from (Baker et al., 1983) may be the best way to describe loading for objects with a diameter up to 1.0 m. In the Gas Explosion Engineering Handbook (J.Czujko, 2001) a simulation shows a good correlation between form drag and loading for a simple example case.

With increasing size of object term two (inertia) and term four (static pressure difference in the flow field) of Equation (1) will gradually become more important, and it is a question to what degree the FABIG TN-08 guidance is valid with increasing object sizes.

The guidance from FABIG TN-08 on how to estimate loads on objects based on CFD-explosion calculations is as follows:

$$Force(t) = \frac{1}{2} C_d \rho A |U(t)| U(t) + (\rho V + m)\frac{\partial U}{\partial t} + \frac{\partial \rho}{\partial t} V U(t) + F_{DP} + F_{HE} \quad (1)$$

Form drag — Accelerated mass — Flame effects — Differential pressure — Oscillations

Object size:	*Proposed method to estimate loads:*
Diameter > 2m	*Direct load measurement (DLM) shall be applied reporting pressure on surfaces (PDF = pressure distribution factor):* $F = \Delta P \cdot A \cdot PDF$ *PDF = 1.0 (box) or* $2/\pi = 0.64$ *(cylinder)*
Diameter < 0.3m	*It is proposed to use form drag formula with conservative drag coefficients from (Baker et al., 1983), i.e.* $C_d = 1.2$ *for cylinder shape. We assume that box shaped elements would use Cd~2.0 (even if Cd=1.05 for a cube)* $F = \rho \cdot v^2 \cdot C_d \cdot A$ C_d *= 2.0 (box shape) or 1.2 (cylinder)*
0.3m < D < 2.0m	*FABIG TN-08 proposes to use form drag formula also for objects up to diameter 1.0m, DNV OS-A101 (2014) proposes its use up to 0.5m diameter, while there is no suggestion in for how to handle objects between 1.0m and 2.0m.*

Here the first term is the form drag, the second term is an inertia term (combined object buoyancy term in an accelerated flow-field/added mass), third term has to do with density changes due to combustion, fourth term is differential pressure in the flow field and the last term is a hydro-elastic term giving potentially increased drag force due to oscillations.

An accurate estimation of explosion loads is important. One should be sure that the load estimates are representative or slightly conservative, but on the other hand excessive conservatism is not optimal as this gives a wrong, non-optimal resource allocation and

For multiple object situations, it is proposed to evaluate pressure loss across the group of objects to estimate the loading.

FABIG TN-08 also proposes a relation between explosion pressure and drag loads. This relation was taken from (Yasseri, 2002), but is later also included in tabulated form in DNV recommended practice (DNV-RP-D101, 2008 and DNV OS-A101, 2014). This way it is possible to estimate drag loads on piping and other small equipment from explosion studies where only overpressure is known.

The purpose of the study presented is to evaluate the accuracy of the currently used methods for explosion load predictions relevant

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